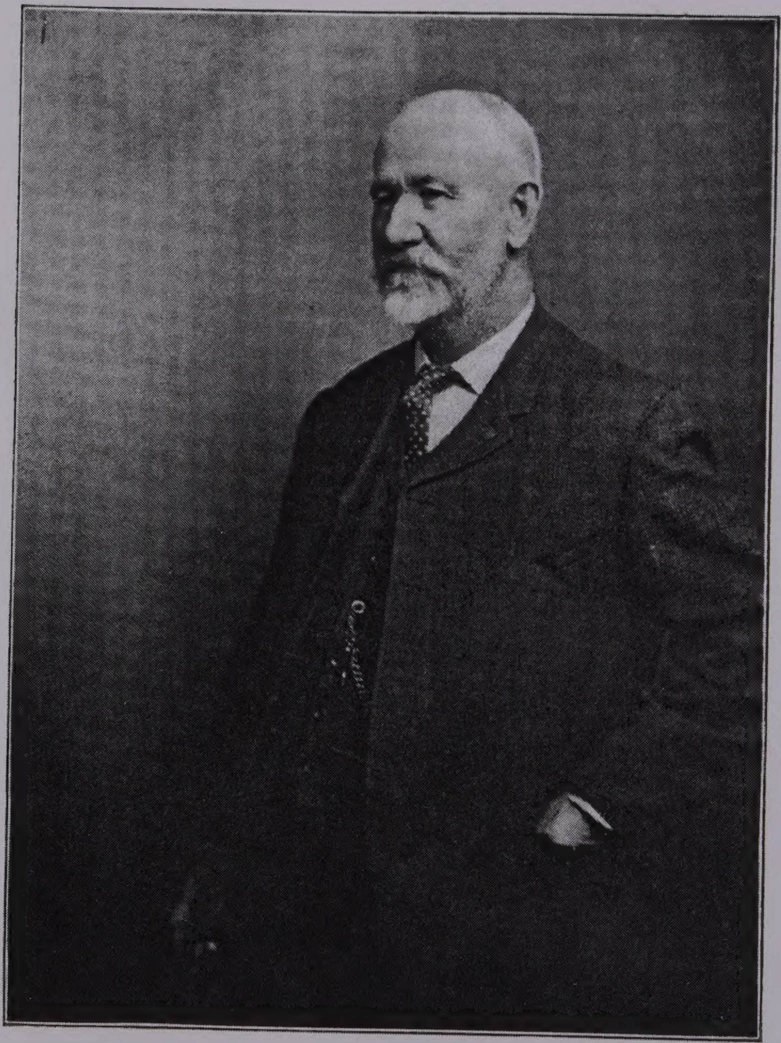
The Physical Geography, Geology, Mineralogy And Paleontology Of Essex County, Massachusetts...

John Henry Sears, Essex Institute

The Physical Geography, Geology, Mineralogy And Paleontology Of Essex County, Massachusetts...

John Henry Sears, Essex Institute



John Henry Sears

THE PHYSICAL GEOGRAPHY GEOLOGY, MINERALOGY AND PALEONTOLOGY

OF

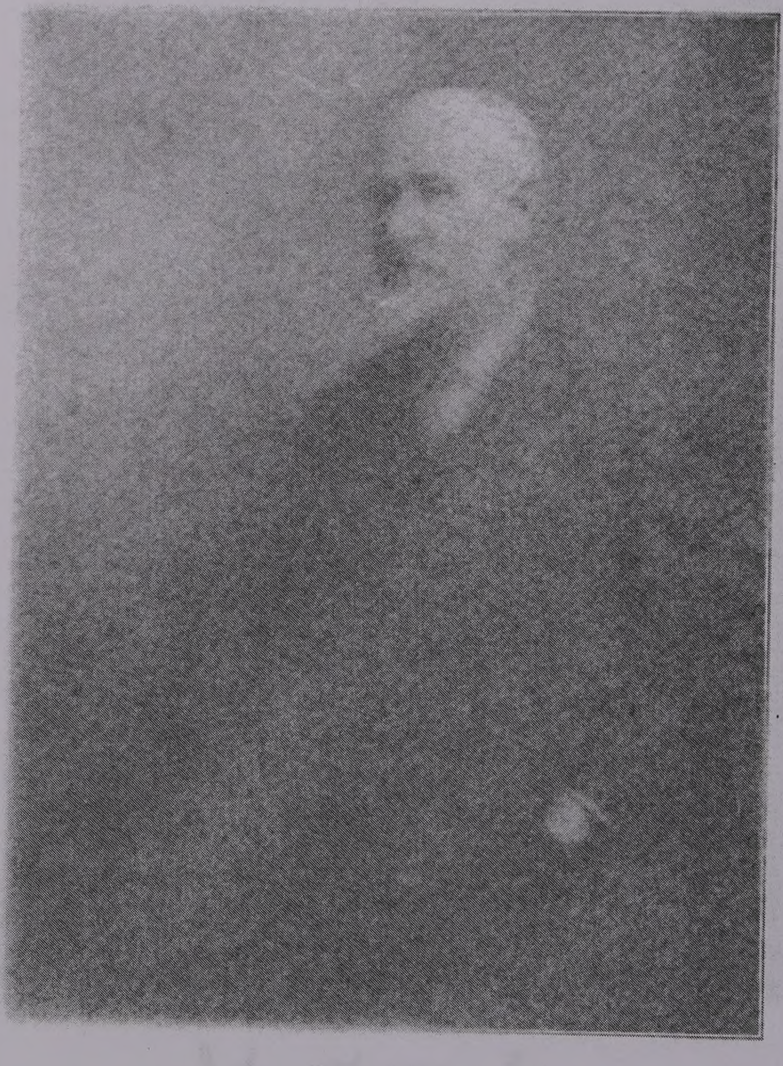
ESSEX COUNTY, MASSACHUSETTS

BY

JOHN HENRY SEARS

CURATOR OF GEOLOGY, MINERALOGY, AND
AT THE PEABODY MUSEUM
SALEM, MASS.

SALEM:
PUBLISHED BY THE [illegible]
1905



THE PHYSICAL GEOGRAPHY GEOLOGY, MINERALOGY AND PALEONTOLOGY

OF

ESSEX COUNTY, MASSACHUSETTS

BY

JOHN HENRY SEARS

Curator of Geology, Mineralogy, and Botany
at the Peabody Museum,
Salem, Mass.

SALEM, MASS.
PUBLISHED BY THE ESSEX INSTITUTE
1905

TO

DAVID PINGREE

THIS VOLUME IS DEDICATED IN
APPRECIATION OF HIS UNFLAGGING INTEREST
AND GENEROUS ASSISTANCE

PREFACE

TWELVE years ago, at the request of the Trustees of the Peabody Academy of Science, I began work upon a preliminary map of the bed-rock of Essex County, which was published in 1894 in the Bulletin of the Essex Institute. In the meantime I prepared a number of short papers which were also published in the Bulletin, under the general title of "Geological and Mineralogical Notes." Since 1894, the work of mapping the outcrops of bed-rock in the County has been continued and the superficial deposits of sand, gravel, till, clay-beds, peat-deposits and silts have been plotted with the greatest possible accuracy. With the exception of such areas as are under water, every sixth of a mile in the entire County has been examined several times by ranges running from east to west and also from north to south. In the determination of the rocks, over eight hundred thin sections have been prepared, the larger portion of which are preserved, together with the rock specimens, in the cabinets of the Peabody Museum. The results of this close examination of the surface are presented in the following pages. The physical geography of the County is described and much space has been devoted to the surface features. The outcrops of bed-rock are superficially described in the text, and at the end of the volume a map will be found on which the deposits of boulder-till, gravel-terraces, sand-plains and other features are represented together with all outcrops of bed-rock. The points of the compass indicated are according to the magnetic compass, its variation from the true north in this region in 1898 being 12° 7′ west.

To Dr. Henry S. Washington, of Locust, New Jersey, I am indebted for chemical analyses of many of the rocks, especially those in the syenite group. I also would acknowledge my obligations to Dr. William H. Dall, of the United States Geological Survey, for assistance in determining the

leda marine clay fossils; to Prof. A. E. Verrill, of New Haven, Conn., for identifying the starfish found in the marine clay at Lynn; to Mr. J. A. Cushman, of the Boston Society of Natural History, for his excellent drawings of fossils; to Prof. Charles D. Wolcott, Director of the United States Geological Survey, for his assistance in naming several of the Cambrian fossils, and also for aid in the construction of the geological map; and to Mr. Richard A. Hale of Lawrence, Mr. John L. Gardner, 2d, of Boston, and others, for photographs used in this volume. My thanks are also due to Mr. John Robinson, of the Peabody Museum, for his interest and early encouragement of my work; to Prof. Edward S. Morse, Director of the Peabody Museum, for valuable advice in relation to the paleontology of the County; and to Mr. George Francis Dow, Secretary of the Essex Institute, for assistance in revising my manuscript. Lastly, my most grateful thanks are due to Mr. David Pingree, of Salem, without whose generous aid this work would not have been accomplished. It is also a pleasure to record my appreciation of the spirit of coöperation displayed by landowners and others in all parts of the County, and my thanks are also due to Mr. Woodbury Page Conant, of Salem, and Mr. Joel Kimball, of Beverly, as well, who have accompanied me on many long walks in out-of-the-way places and in the northern part of the County.

CONTENTS

LIST OF ILLUSTRATIONS

Fig. 2.—MERRIMAC RIVER AT THE LAWRENCE DAM.
Winter of 1897.

Fig. 3.—MERRIMAC RIVER AT THE LAWRENCE DAM.
During a spring freshet.

THE PHYSICAL GEOGRAPHY, MINERALOGY, AND PALEONTOLOGY OF ESSEX COUNTY, MASSACHUSETTS

CHAPTER I

PHYSICAL GEOGRAPHY

Essex County, Massachusetts, is situated between latitude 42° 53′ 10.49″ north, and 42° 25′ 09.20″ south; and between longitude 70° 34′ 46.28″ east, and 71° 15′15.33″ west. The County contains 355,840 acres, of which 21,789 acres are tidal marsh covered by sea-water at high tide; 18,000 acres are covered by sea-water in the form of bays, harbors, and drowned river valleys; and 16,500 acres are covered with fresh-water ponds, lakes, rivers, and swamps; leaving 299,551 acres occupied by city and village sites, woodlands and tillage lands.[1] The number of acres within the territorial limits of each town and city is inserted as Appendix A.

Watersheds. — The principle watersheds in the County are in the valleys occupied by extended streams: the Saugus river at the south, the Ipswich and Parker rivers flowing across the central part of the area, the Merrimac river in the northern part of the County, and a number of small tributaries which empty into the extended streams, together with a few small streams rising near the coast-line and emptying into the sea. Examples of the latter are: Mill brook, which rises in a swamp one mile north of Pride's Crossing and empties into the sea between Beverly Farms and West Manchester; Beaver Dam and Saw Mill brooks in Manchester; and Frost-fish brook, Danvers, which empties into Porter's river, a drowned river valley or tidal stream flowing in and out through Beverly harbor.

Several interesting divides in these streams show almost exactly the height of land, which is remarkable as the water fall is very slight. The valleys are nearly level and the streams flow sluggishly except in times of flood. One of these divides occurs in a meadow in Danvers, in the valley

[1] In 1905, there were seven cities and twenty-eight towns in the County.

between Goodale's and Fair Maid hills. During the winter the ice forming over the surface becomes frozen into a mound. A small brook which makes its way from this mound flows to the eastward and supplies the head-waters of Crane's river which flows to tide-water at Danversport. Another brook which rises from this ice mound, flows westerly and joins Boundary brook between Danvers and Peabody and empties into the Ipswich river in Danvers. Another similar divide occurs in Topsfield, south of the Ipswich river, near a contact of the hornblende granite with the diorite and the Cambrian limestones. In a small meadow south of Pingree's hill, a brook rising from a spring flows westerly under Hill street and Rowley Bridge street and empties into the Ipswich river. Another brook starting from the same meadow flows easterly under the Boston and Newburyport turnpike, thence across the northern part of Danvers to Wenham swamp, and then into the Ipswich river. Similar divides in the watershed may be found in several towns in the County.

Springs. — All the streams in the County flow from springs, often called boiling springs because the water bubbles up with considerable force through the sand or gravel in the bottom of the spring. Great spring, in Blind Hole swamp, Danvers, rises through eight feet of peat, sometimes bringing to the surface pebbles an inch in diameter. The water in these springs is always soft, and percolates through sand and gravel soils from a bed-rock of either granite, diorite, granitic gneiss or metamorphosed slate. There are two or more chalybeate springs in the County, one of which is at Montserrat, Beverly, and another at the Mineral Paint mine in Georgetown. The water comes to the surface through syenite and slate rocks containing masses of iron pyrites, lime, soda, feldspar, and calcite. These minerals when dissolved furnish the silica, carbonate of lime, soda, sulphur, and iron which appear upon analysis. At Ballardvale, in Andover, is the well-known Ballardvale Lithia spring. The bed-rock of the region is a coarse granitic white gneiss containing an abundance of crystals of white lithia mica, which are dissolved by the carbonic acid in rain-water and little by little impregnate the spring-water.

The spring-waters in the County are always good and wholesome, containing only about one part of dissolved mineral substance in every 10,000 parts of the water. In 1903, there were seventeen springs from which mineral waters were sold for table use, and numerous springs from which waters were bottled for domestic purposes.

These springs and streams played a very important role in the settle-

Fig. 4.—MERRIMAC RIVER AT MITCHELL'S FALLS.
During low water, Oct. 3, 1897.

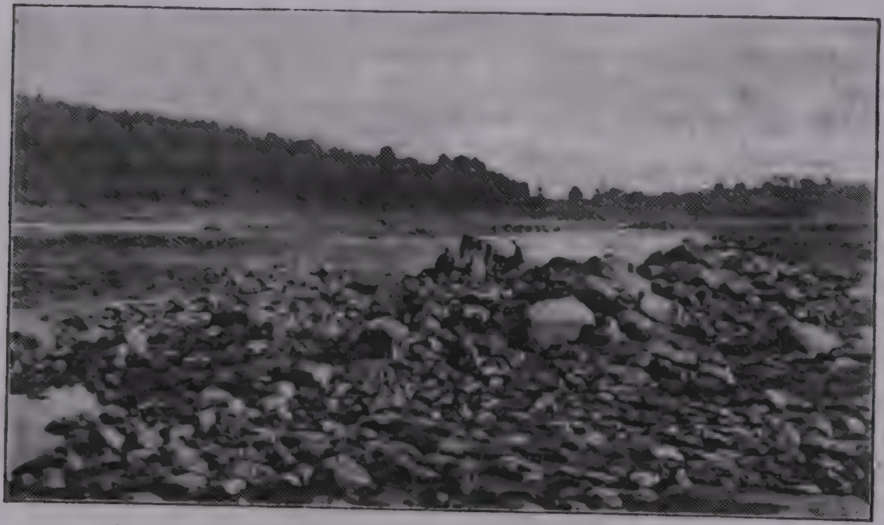


Fig. 5.—MERRIMAC RIVER AT MITCHELL'S FALLS DURING LOW WATER, 1897.
Kimball's island at the right.

Fig. 6.— MOUTH OF THE SPICKET RIVER, LAWRENCE

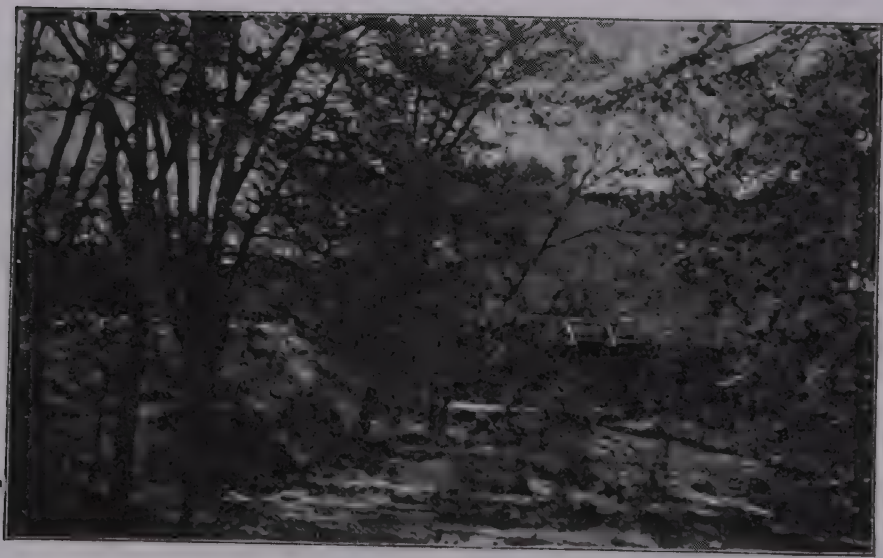


Fig. 7.—SPICKET RIVER BELOW THE GLOBE MILLS DAM, LAWRENCE.

ment of the County, for the early settler always chose a site for his house near a spring. As a town was formed, the burial-ground, the meeting-house, the school-house, and the townhouse were usually built upon a sandy waste or a sand-plain where the soil was poor and unfit for cultivation and in time such locations became proverbial. Later, with the introduction of aqueduct water, these sand-plains became the sites of villages surrounding the public buildings.

Drainage and Formation of Valley Systems. — In the Cambrian, Pre-Cambrian and Archean periods, the longer axes of all of the crystalline rocks were formed approximately in the line of strike of the Archean gneissic and the Cambrian sedimentary rocks. This trend is northeast to north, and southwest, and the principal streams and their valleys accordingly follow this general course. The younger or consequent stream valleys are those which cut across the strike of these gneisses and sedimentary rocks.

River Systems. — The principal river systems in the County, with valleys of the extended type, are as follows:

First: the Merrimac, an extended stream which takes its course across West Andover to Lawrence, Bradford and Haverhill. (See Figs. 2, 3, 4, 5.) From thence in its flow to tide-water it very nearly follows a northeasterly course, being deflected occasionally by hard dike rocks which cut across the stratified beds. At Amesbury, the Powow river, a consequent stream, empties into the Merrimac at Salisbury Point. The Merrimac is here forced to cut its channel southeasterly to avoid a massive outcrop of porphyritic granite, while along its southern bank there is a line of contact of the Cambrian sediments and the quartz augite diorite rocks extending to the mouth of the river.

Second: the Shawsheen river, a consequent stream of somewhat extended type, which flows its entire course, a distance of twenty-five miles, northeasterly from the town of Lincoln, in Middlesex County, to South Lawrence, where it empties into the Merrimac.

Third: the Spicket river, also a consequent stream, which is the outlet of Youth's pond and Mystic pond in Methuen. (See Figs. 6, 7.) It flows northeasterly across the northern part of Methuen, then south-southeasterly to Mystic pond, and then meanders in a southeasterly course across the southern part of Methuen to the city of Lawrence, there flowing along the strike of the metamorphosed slate beds to the Merrimac river.

Fourth: the Ipswich river, which is of the extended type and rises in the meadows of Wilmington and Burlington, winds its course in a north-

easterly direction through meadows in the line of strike of the Cambrian limestone slates and conglomerates in the town of Reading and then through Middleton and Topsfield to tide-water at Ipswich. (See Figs. 8, 9.)

The Parker river is also of the extended type. It is the outlet of Chadwick's pond in West Boxford and flows southerly and then northeasterly through Georgetown, West Newbury, and Newbury, at last emptying into Plum Island river.

Essex river, the outlet of the Chebacco lakes, is an extended stream that rises in East Wenham and flows toward the northeast, draining the whole region of East Hamilton, Manchester, and Essex. On this stream there is a twenty-foot fall known as Essex Falls, where there is a sawmill.

Other consequent streams are:

Miles river, the outlet of Wenham lake, and Pleasant pond brook, the outlet of Pleasant pond. Both flow north and northeast and empty into the Ipswich river at Hamilton and Ipswich. Black brook, the outlet from Cutler's pond, flows northerly, and after many meanderings also empties into the Ipswich river at Hamilton.

Nichols' brook, in Danvers, drains Bishop's and Peters' meadows and flows northeasterly through Middleton to Topsfield where it empties into the Ipswich river.

Beaver brook, in West Newbury, flows southerly and southeasterly across the town, east of Crane Neck hill, and empties into the Parker river.

Mill creek, the dividing line between Rowley and Newbury, at the beginning of its flow is known as the Great Swamp brook, but at South Georgetown it is called Mill river. Its course is southeasterly for the first mile and then northeasterly for a distance of eight miles to Dummer's mill. With several wide detours it then flows northeasterly and empties into the Parker river.

Bull brook, rises from a series of springs in Pine swamp, Ipswich, and flows northeasterly through the town of Rowley into Rowley river.

Boston brook, rises in Andover and flows three miles in a southeasterly direction, then turns toward the north for a mile, and then to the southeast, flowing four miles in this course with several wide meanders, to Middleton where it empties into the Ipswich river.

Mosquito brook also starts from a spring in Andover on the westerly side of Woodchuck hill, and after flowing about five miles in a northeasterly course empties into Fish brook, which flows through Boxford toward the southeast in a winding course and empties into the Ipswich river at Topsfield.

Fig. 8.—IPSWICH RIVER AT THE MIDDLETON PAPER MILL DAM.

Fig. 9.—IPSWICH RIVER IN MIDDLETON.
As seen from the bridge on the Danvers road.

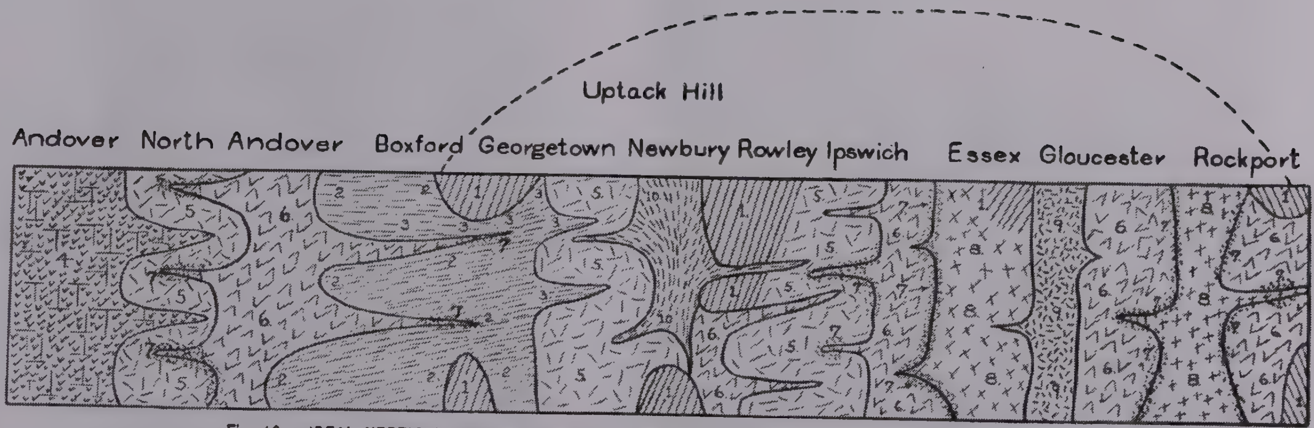


Fig. 10.—IDEAL VERTICAL-SECTION ACROSS ESSEX COUNTY, SHOWING SECTIONS OF THE ERUPTIVE, VOLCANIC, AND SEDIMENTARY ROCKS.

The dotted dome-shaped line represents a reconstruction of the ancient Cambrian mountain, the anticline.

1. Olenellus Lower Cambrian rocks,—slates, sandstones, limestones, and quartzites.
2. Foliated quartz hornblende diorite.
3. Hornblende epidote gneiss.
4. Muscovite biotite gneiss, white gneiss, and muscovite biotite granite.
5. Hornblende diorite.
6. Hornblende granite.
7. Micrographic granite.
8. Akerite and hornblende syenite.
9. Nordmarkite.
10. Aporhyolite.

Howlett's brook and Mile brook flow from springs in Boxford and follow a southeasterly course into Topsfield where they empty into the Ipswich river.

The stream which forms the outlet for Cape pond, at Rockport, flows southwesterly across Gloucester and empties into Mill river at Willowdale in Gloucester. Another brook which rises in a swamp at Rockport near the Boston and Maine Railroad station, flows northeasterly through the village of Rockport where, south of King street, it forms a pond on which ice is cut for domestic purposes. This brook empties into the sea at Sandy Bay, there showing that the tilt of the granite anticline, on the extreme point of Cape Ann, is toward the northeast.

All of these consequent streams are of sluggish flow with very slight fall and meander through swamps, meadows, and old ponds in wide valleys and sand-plains.

South of Essex County, in Middlesex County, the Concord and Sudbury rivers flow north to northeast and empty into the Merrimac river at Lowell, also demonstrating that the slope or tilting of the land surface of Essex County and the northern part of Middlesex County is toward the north and northeast. This is in an opposite direction from the supposed slope of the land south of Cape Cod and also in the Connecticut river valley. The northeasterly to southwesterly valleys of the Concord, Shawsheen, Ipswich, and Merrimac river systems signify that they flow in a series of broadly sweeping synclinal folds of the old Archean gneissic rocks and Cambrian sediments. Measurements across the upturned edges of the Cambrian rocks found in Essex County prove that they were over 10,000 feet thick, and if reconstructed would form mountains fully two miles in height over our granite syenite and other igneous rocks. (See Fig. 10.) To quote from Professor Van Hise, in his "Principles of North American Pre-Cambrian Geology":[1] "It has been shown that at a depth of 30,000 feet, more or less, even the strongest rocks must find relief from stress by flow, and hence below that depth there must be a zone, which, as respects its manner of deformation, may be called a zone of flow." If this statement of Professor Van Hise is correct, very probably this depth to the zone of flow may have been under our Cambrian rocks which are now near the present surface. Should this be the case, the flow and crumpling of the granite gneiss and foliated quartz diorites, which is to be seen in the central part of the County, may have been formed in this zone of flow beneath the Archean and Cambrian sediments, which were

[1] 16th Annual Report of the United States Geological Survey, Pt. I, pp. 594–598.

base-levelled or cut down to the level of the sea long before the Tertiary uplift which ushered in the Quaternary or Pleistocene period.

Surface Features. — Essex County, and indeed the whole of eastern Massachusetts, has an uneven surface with numerous outcropping ledges of bed-rock which are either base-levelled or have an elevation varying from fifty to one hundred feet above mean sea-level. The summits of these elevations are bare or have but a slight covering of soil. There are a few higher elevations of bed-rock rising to about two hundred feet in height and known as "Monadnocks." Such isolated peaks are remnants of the hard rocks of an ancient Peneplain, which have withstood the erosive forces which have cut down and produced the valleys between them.

The Cambrian rocks are in part base-levelled. They are usually seen in the bottoms of valleys, or, at some contact with later intrusive rocks, which have turned the Cambrian sedimentary beds upon their edges so that they now stand nearly vertically. In the valleys away from such contact, they are found to dip at an angle of from 40° to 48°. These rocks invariably contain fossil *Hyolithes*. A study of the Cambrian rocks leads to the conclusion that this region was not coastal at the opening of the Olenellus Lower Cambrian epoch as these fossiliferous rocks are found in the bed of the sea as far out as Jeffrey's bank which is fifty miles from the present shore-line. It is also well known that they occur beyond Cape Sable off the coast of Nova Scotia.

Peat Deposits. — Deposits of peat occur in nearly every town in the County and more particularly in Danvers, Middleton, Topsfield, Boxford, Georgetown, and Wenham. From a careful examination it is estimated that over 21,000 acres of peat may be found in Essex County exclusive of the submerged deposits below sea-water at high tide. The great Wenham swamp covers an area of some two thousand acres, nearly all of which is a forest-grown peat deposit from nine to eleven feet in thickness. At the Longham basin, an artificial feeder of Wenham lake, the peat was found to be over fifteen feet in thickness. The deposits surrounding the ponds at Legg's hill are eleven feet deep, and in various parts of the County they are found to be from five to nine feet in thickness. If this peat were made into coke it would supply fuel of excellent quality and of great value for domestic use, and as these deposits are continually being formed, an almost inexhaustible supply is always available for local use.

Geological Distribution of Plants. — Certain plants have their highest development on certain kinds of soil and are dependent upon the chemical character of the bed-rock of the region in which they are found growing.

Fig. 11.—CHESTNUT TREES (CASTANEA AMERICANA).
Growing upon hornblende granite soil on the Burley farm, Danvers.

Fig. 12.—BEDDED SLATES AND LIMESTONES AT EAST POINT, NAHANT

Fig. 13.—HORNBLENDE GRANITE HEADLAND AT EASTERN POINT, GLOUCESTER.

The rock formation possessing the largest percentage of silica, with an alkali, potash, alumina feldspar, such as the hornblende granite, produces finer specimens of certain kinds of plants than will grow upon rocks having a lime, soda, alumina feldspar, composition such as the hornblende dorite or the augite syenite. The latter is a rock with a low silica ratio, but having a soda, lime, potash, alumina feldspar, and when in contact with hornblende granite, it is difficult to distinguish the one from the other. The feldspars in the two rocks, however, are chemically quite distinct and a marked change occurs in plants growing on the two formations, even in limited areas such as points of contact. To illustrate—at the corner of Essex and Grapevine streets, East Wenham, on the Rubbly hills, which are augite syenite, the red cedar, *Juniperus Virginiana*, grows equally as well as on the hornblende diorite areas where it has its greatest development. On the hornblende granite formation at the north and east of the Rubbly hill area, the red cedar is never found growing.

Lime or calcite is a common constituent of many slates, as well as in the diorite rocks, and in the flora of lime-rock soils a marked change is noticed from that found upon rock formations that are rich in silica. This is also true of alkali, potash, alumina bed-rock, whether it be granite or volcanic aporhyolite. The common rue anemone, *Syndesmon thalictroides*, is abundant on the hornblende diorite slate and limestone areas, but it is rarely found growing in the hornblende granite soils. *Anemone riparia* is also common on the lime, slate, and diorite soils in Topsfield and Boxford, but is unknown on the acid hornblende granite soils. Pink corydalis, *Corydalis glauca*, is a common plant found growing on nearly bare hornblende granite ledges, but it is unknown on the diorite or limestone areas in the County. The round-leaved violet, *Viola rotundifolia*, is occasionally found growing on granite areas, but never on the diorites or limestones. The tick-trefoils, *Desmodium*, are common plants in the woods on the augite syenite, diorite, slate, and limestone formations, but are very rarely found on the granite areas. Dwarf cherry, *Prunus pumila*, grows abundantly on the granite soil in South Peabody, but is unknown on syenite or diorite soils. The three-toothed cinquefoil, *Potentilla tridentata*, may be seen growing in the granite soil at Gloucester and Rockport. It is rare, however, in the syenite soils and is unknown in the diorite areas.

Bristly sarsaparilla, *Aralia hispida*, grows in great abundance in the granite soils, but is rare or unknown on the diorite areas. Red-berried

elder, *Sambucus pubens*, is common at Gloucester and Rockport on granite, but is rare on syenite and unknown on the diorite areas. The blue-stemmed golden-rod, *Solidago cæsia*, is common on granite and aporhyolite areas and rare on diorite, while showy golden-rod, *Solidago speciosa*, is common on diorite and syenite areas and rare in the granite regions. The yellow thistle, *Cnicus horridulum*, is common at Rockport on the hornblende granite and unknown on the diorite. The cowberry, *Vaccinium vitis-idæa*, is only found growing on diorite and slate regions in Danvers and Topsfield. The bearberry, *Arctostaphylos uva-ursi*, is common in the granite soil of Peabody, Beverly, Manchester, and Rockport, but is unknown in the diorite or lime-slate localities. Red cedar, *Juniperus Virginiana*, and low juniper, *Juniperus communis*, are both very common on the diorite, augite syenite, and lime-slate areas in all parts of the County from Saugus to Rockport, and northwesterly to Methuen, but the first has never been observed upon a hornblende granite area. Black Ash, *Fraxinus sambucifolia;* white cedar, *Chamæcyparis sphæroidea;* hobble-bush, *Viburnum lantanoides;* red maple, *Acer rubrum;* and white maple, *Acer dasycarpum*, all grow almost exclusively on peat and river-silt soils and are not affected by bed-rock soils. Many other plants are common to one kind of soil, which apparently seems due to the chemical character of the bed-rock.

Fig. 14.—GAP HEAD AND STRAITSMOUTH ISLAND, ROCKPORT.
Showing an augite syenite contact with hornblende granite.

Fig. 15.—SQUAM RIVER FROM WEST GLOUCESTER.
Showing tidal marshes.

Fig. 16.—TIDAL MARSH AT ROWLEY.
View from the railroad at high tide; Plum island in the distance.

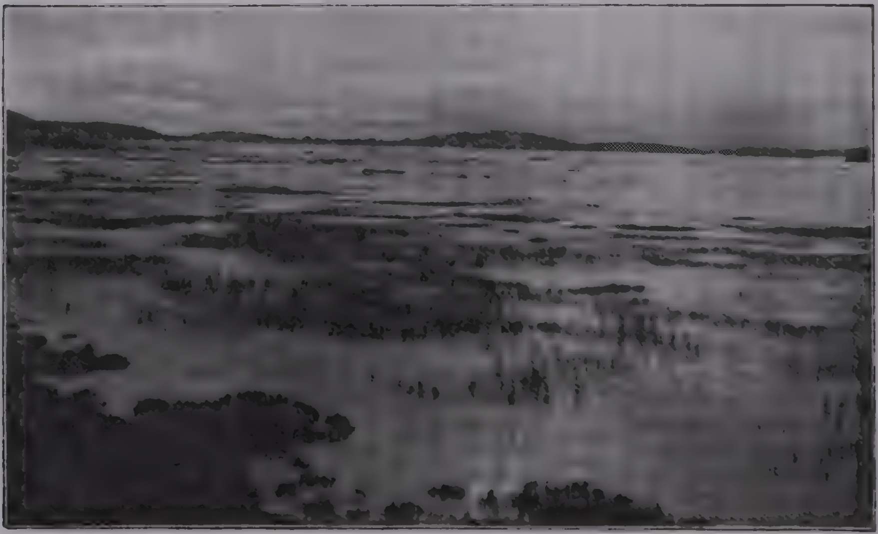


Fig. 17.—LAGOON WEST OF JEFFREY'S NECK, IPSWICH.
Showing tidal marsh and drumlins in the distance.

CHAPTER II.

COAST-LINE TOPOGRAPHY

Rocky Headlands. — The bedded sedimentary slates and limestones of East point, Nahant, show somewhat rectangular outlines while the massive crystalline igneous intrusive rocks at Little Nahant, and elsewhere on the coast, assume particularly rugged, broken, and bizarre forms among which are rarely seen traces of the rectangular outlines commonly present on shores where bedded rocks occur. (See Figs. 12, 13, 14.)

The general tendency of marine erosion is to eventually reduce irregularities, cut back headlines, and fill the intervening bays with silt. Bars or ridges are thus formed across the mouths of estuaries and other notable indentations of the land, which eventually are closed more or less completely. Hence, all seacoasts, which can be shown to be of relatively great age, have a gently sinuous or profusely curved outline, and conversely, highly indented coasts are of recent origin, for the sea has not had sufficient time to reduce their irregularities.

Smooth or Regular Coast-Lines. — These may be high and steep or low and gently shelving, the one kind often alternating with the other. In some places the cliffs project boldly beyond the average coast-lines and form headlands; elsewhere, they curve backwards, or their continuity may be interrupted by more or less numerous creeks or small inlets.

When the joint plains of the bed-rock of the shore are somewhat regular, as in the slates, limestones, and some granites and basalts, the mural, or wall-like cliffs may appear; while where diorite, syenite, and the crystalline schists form the bed-rocks of the coast, they exhibit every variety of form except the rectangular. From Cape Ann northward and along the coast-line of New Hampshire and southern Maine the shore is gently shelving and regular, softly sinuous in outline, and exhibits a succession of broad, evenly curved bays. These bays are separated by low capes and headlands, broadened by banks of beach sand, sand-dunes, and beds of gravel, behind which appear salt or brackish water lagoons and salt marshes. These lagoons sometimes take the form of shallow deltas obviously owing their origin to the action of the rivers and small streams

(see Figs. 16, 17), but the drift materials carried shoreward by waves and tidal currents are a main factor in filling up these lagoons. The drift carried to the sea by a stream does not always accumulate opposite its mouth, for tidal currents often prevent the rapid growth of a delta by sweeping away much of the drift material and depositing it along the shore. This is especially noticeable at the mouth of the Merrimac river, at Newburyport, where most of the drift brought down by the river is deposited on Plum island to form off-shore bars.

Drowned River Valleys Due to Subsidence. — Coastal plains are the result of crustal movements and all highly indented coast-lines are evidence that the land is being submerged and is consequently sinking. The coast of Essex County is an example, which is further shown by the numerous drowned stream valleys, the tide-water inlets, and the peninsulas and fringing islands which abound on the rocky shores. These features are especially noticeable from Cape Ann southward to Chelsea creek, and also extend over the whole Boston-Charles river area and southward to Cape Cod. For an excellent example of a drowned river valley, the Parker river below the dam at the Byfield woolen mills should be examined. (See Figs. 18, 19.) There is approximately the same height in the rise and fall of the tide at that point as at Plum Island sound, nine miles from the mouth of the river. The tidal marsh at Ipswich, Rowley, and Saugus should also be noted as exhibiting a drowned topography due to subsidence. (See Figs. 15, 20, 21.)

Plum island at the north is an example of glacial morainic hills, probably a series of drumlins, that are very nearly base-levelled by sea wave-action due to subsidence. The bases of these morainic hills reach out into deep water. Emerson's rocks, which are forty to sixty yards from the present shore of Plum island, are an example of one of these base-levelled drumlins. Back from the drumlins, which are now covered with Post-Pleistocene wind-blown sands and sand-dunes, lagoons and tidal marshes have formed, reaching westerly to Ipswich and Rowley and covering a space of at least five hundred acres. The morainic drift boulder-till of the drumlins was formed during the early Glacial period. The erosion of this boulder-till by marine action is still going on, as a visit to the southern end of Plum island at high tide will demonstrate, for the tide-water is turbid with clay sediments eroded from the base of the drumlin at the "Bluffs." This must be caused by subsidence, for there would be marine deposition of sand and gravel at the base of the "Bluffs," if elevation were going on at present instead of marine wave-erosion.

Fig. 18.—PARKER RIVER, BELOW THE BYFIELD WOOLEN MILLS.
At low tide.

Fig. 19.—PARKER RIVER BELOW THE BYFIELD WOOLEN MILLS.
At high tide.

Fig. 20.—SAUGUS RIVER MARSHES AT HIGH TIDE.
Showing drowned topography due to subsidence.

Fig. 21.—SAUGUS RIVER MARSHES AT HIGH TIDE.
From the Lynn and Boston turnpike, looking towards Lynn.

The numerous islands and small bays, the drowned valleys covered by water at high tide, and the amount of land surface that is covered by sea water at high tide, 39,788 acres, all indicate that the area covered by the County has been sinking. Tide-water flows up the Merrimac river, resulting in a rise and fall of five feet at Groveland bridge, sixteen miles from the mouth of the river. At the dam of the Byfield Woolen Mills on the Parker river, nine miles from Plum Island sound, there is a rise of eight to ten feet. The Ipswich river, Plum Island river, Squam river, Castle Neck river, and Porter's, Crane, and Waters' rivers at Danvers, are all typical streams or drowned valleys in which the water flows out at low tide. (See Figs. 15, 22, 23, 25.) Chelsea creek, the boundary between Essex County and Suffolk County on the south, is a tide-water brook, and Saugus river is another example of the drowned valley. These streams all illustrate drowned topography in a youthful stage of development.

Subsidence. — Evidences of subsidence are clearly shown along the entire coast-line in many sheltered coves. At Nahant, in the cove between Bass point and the steamboat landing, covered by thirteen to sixteen feet of water at high tide, may be seen numerous stumps of several species of forest trees. Among those which are well enough preserved to be determined are white pine, swamp or white cedar, hemlock, spruce, ash, oak, and maple. The roots of these trees are found in original leaf-mold and peat-beds, from one to three feet in thickness, which rest upon a very tenacious, slippery, blue clay of unknown depth, the leaf-mold and peat-beds being covered by washed sand and stones of all sizes in a stratum of varying thickness. There are several other places at Nahant where peat-beds are seen at or near low-water mark. (See Fig. 27.) One, in the southwest cove of Crescent beach, is quite extensive and contains many logs and stumps of old forest trees; another, on the northwest side of Little Nahant, is of a similar character. Lynn harbor and the marshes of Saugus furnish numerous examples of old peat-beds in which large logs of pine and oak lie imbedded below the recent accumulation of marine peat and salt-grass roots.

On the Beverly shore, between West's beach and Misery island, are many stumps of forést trees which may be seen at low tide, when the water is clear and still, at a depth of twelve or fourteen feet. A piece secured from one of these stumps proved to be white pine.

In a cove near Chubb's island, Manchester, at a depth of eleven feet below high-water mark, are the remains of an oak stump, which, now

divested of the sap-wood, is twelve feet in diameter inside the buttresses, representing the tree at its full growth in this region. In Manchester harbor, inside of the Ram islands, stumps of white pine and oak are found in the original leaf-mold and peat-beds covered by washed sand and rocks as at Nahant.

On Kettle Cove beach, Manchester, submerged stumps are visible at low water during the spring tides. Near the old road-bed, inside of Crow's island, the marine peat and salt-grass roots are from ten to fourteen inches in thickness. Directly under the marine peat is a bed of leaf-mold and fresh-water peat from three to four and one-half feet in thickness, in which are found numerous logs of pine, spruce, and white cedar and the branches of the ground yew, *Taxus Canadensis*, the last named remaining in its normal prostrate position. Below the peat are large oak stumps standing in the glacial drift where the trees formerly grew. While securing a specimen of one of the larger oak roots, scratched pebbles and grooved stones were found with oak roots growing around them in their natural position. From these observations it would appear: (1) That the ancient oaks grew on the glacial-till which became depressed; (2) that a lake formed on this area in which accumulated the peat and leaf-mold upon which grew the pine, cedar, spruce, and ground yew; (3) that this in turn became submerged and the marine peat and salt-grass formed above it; (4) and lastly, that the seaward slope has become so great that the waves are cutting into and carrying away these earlier formations and thus exposing them to view.

Red cedar stumps have been found at Mingo beach some of which are six inches in diameter, only the heart-wood remaining. With these were many logs of spruce and hemlock ramified by the borings and containing shells of *Petricola pholidiformis*, a mollusk abundant in the peat and clay of this beach. (See Fig. 26.) The peat at this point is five and one-half feet in thickness, or fourteen and one-half feet below high water to the bottom of the peat as seen on the beach. In this peat hundreds of wings of water-beetles and a great many fragments of other insects have been found, together with roots of the cow lily, white pine cones, oak acorns, spruce cones, and roots, logs, and stumps of spruce, hemlock, pine, and oak mixed in great confusion.

Salem harbor furnishes additional evidence of subsidence, and sunken stumps of forest trees have been observed at Phillips' and King's beaches in Swampscott, and also at Marblehead beach, while the beaches and marshes of Ipswich, Rowley, and beyond furnish similar deposits. Speci-

Fig. 22. — WATERS RIVER, DANVERSPORT, AT LOW TIDE
Beverly shore in the distance.

Fig. 23. — CRANE RIVER, DANVERSPORT, AT NEARLY LOW TIDE.
Showing the meandering of the stream.

Fig. 24. — FOREST RIVER, SALEM, AT LOW TIDE.
Jeggles' island in the foreground and Legg's hill in the distance. The tide rises here from 8 to 14 feet.

Fig. 25 — FOREST RIVER SALEM, ABOVE THE DAM, AT LOW TIDE.
From Legg's hill

mens have been collected from the stumps in many of the places referred to above and may be seen in the museum of the Peabody Academy of Science at Salem.

In 1894, soundings were made in Salem and Marblehead harbors for the purpose of comparing the depths of the water over certain rocks with those given in the report and on the chart prepared by Dr. Nathaniel Bowditch in 1804 and 1805. Dr. Bowditch stated that the summit of Boden's rock was seven feet below low water on the full and change of the moon, taken from easily recognized compass points on the mainland and islands in the harbor. Soundings taken on this spot, under similar conditions, July 17, 1894, gave nine feet of water; and again, August 1, 1894, gave eight and one-half feet of water. These soundings were made with care, and offer evidence of a subsidence in the past ninety years of at least one and one-half feet at this point.

Dr. Bowditch's report gives five feet of water, at mean low water, on the summit of Privy ledge, three hundred yards outside Orne's island. August 2, 1894, there was seven feet of water at this point, indicating a subsidence of two feet. There is, however, in all probability a greater amount of erosion at this place than on Boden's rock in the harbor. Dr. Bowditch reported six feet of water on the shoalest portion of Abbot's rock, while on August 30, 1894, eight feet of water was found. Taken at low water, August 31, 1894, Archer's rock had eight feet of water; September 1, 1894, Bowditch's ledge had seven and one-half feet; and September 2, 1894, Cut-throat ledge had six feet of water. In Dr. Bowditch's report, six to seven feet of water is given for Archer's rock, which is one foot less than appeared in 1894; Bowditch's ledge had five to six feet of water in 1804–5, where soundings in 1894 gave seven and one-half feet. On Cut-throat ledge, Bowditch gave four feet of water, while six feet was found in 1894 at extremely low water. These soundings indicate a considerably greater depth of water on all of these ledges than existed ninety years ago. This also agrees with the estimate of Prof. W. J. McGee of two feet of subsidence for the century for the entire coast.[1]

From all observations made the evidence points to the conclusion that there has been a subsidence of the land surface of the coast region of Essex County in recent, or, more accurately speaking, in Post-Terrace times, and that this subsidence is still in progress is clearly indicated by

[1] See the Forum, Vol. IX, p. 448; and Bulletin of the Essex Institute, Vol. XXVI, pp. 64–73.

the submerged forest growth and peat-beds and the compared soundings in the harbors.

Sea Beaches. — The incoming tides and littoral currents setting shorewards from the north, transport sediments of sand, mud, and silt from shallow parts of the sea bottom and from along the shore. These sediments are the result of wave-action in cutting backward the headlands and beaches toward the northeast. Such action is now going on at Great Boar's Head and Little Boar's Head in New Hampshire, and on the gravel and sand-banks along the whole shore of the state of Maine. Some of these sediments are no doubt from off-shore sources and are brought along by the Labrador current from points at the north and taken shorewards by tides and littoral currents. Heavy easterly gales cause breakers of great power to cut into exposed ledges and islands, as may be seen at the Isles of Shoals, where the waves cut into and remove large masses of rocks which in a short time are reduced to sand and mud by the action of the sea. This helps to swell the volume of sand and sediment on the beaches of the mainland.

Salisbury beach derives its sand from this source, and more directly from the rocky parts of the shores of Seabrook and Hampton. The prevailing northerly winds drive these sands and sediments southward the length of the beach and then into the swiftly flowing tidal currents of the Merrimac river, where they are actually ferried across its mouth on the Newburyport bar or delta to Plum island. This delta at low tide is covered by only a few feet of water, and over it the tide rushes in and out, causing numerous eddying currents which set towards the shore and carry vast quantities of sand upon the island.

Much of the sediment which forms the delta at the mouth of the Merrimac comes down the river from below the Lawrence dam. During the spring floods, the river cuts into its banks of sand, boulder-till, and gravel at nearly every headland between Lawrence and Newburyport, filling the bed of the river and forming shoals and mud-banks, which are constantly being swept onward by the current and tidal waters to the delta at its mouth, there to swell the vast accumulation of sand and sediment on the sea coast and on Plum island. Large amounts are also spread out over the Joppa flats and carried down Plum Island river to Plum Island sound, Newbury, and Rowley.

Plum island is a bar off the shores of the towns of Newbury, Rowley, and Ipswich. It is about eight miles in length, extending from Newburyport to Ipswich in a series of remnants of drumlins, gravel-banks, and

Fig. 26. — MINGO BEACH, BEVERLY (1894).
Showing submerged peat-beds and logs and stumps of forest trees.

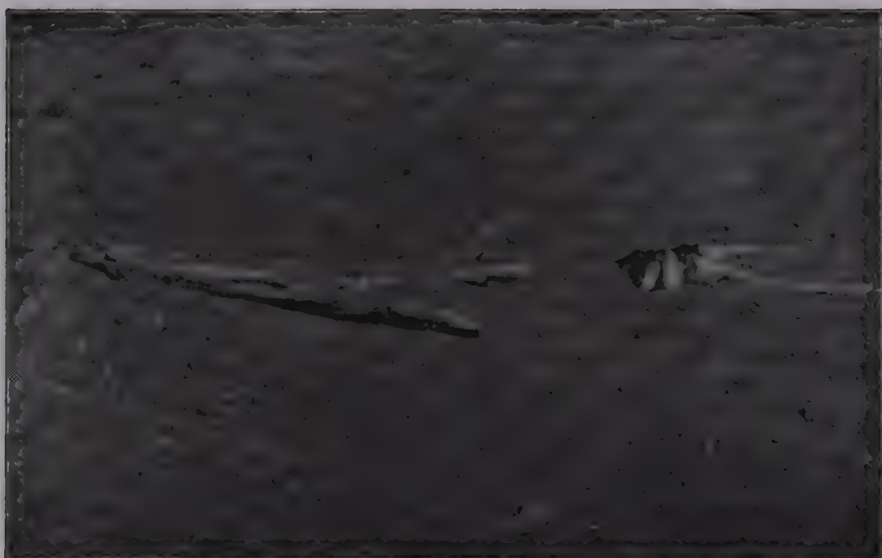


Fig. 27. — POND BEACH, NAHANT (1894).
Showing submerged stumps of white pine trees.

ridges of boulders. The island curves slightly to the southeast on the beach side, while on the inshore side Plum Island river cuts its channel through the salt marsh that covers the old lagoon formed inside of this bar. The greatest width of the island is about one-half of a mile. The sand-ridge at Rowley, and its breaker on the ocean side of the island, which may be seen at low water, are within one hundred yards of the shore (see Fig. 28), except near the delta at the mouth of the Merrimac, where the island and its shoals, at low water, are nearly a mile wide, and also at the southern side of the island, at Ipswich, where the outer breakers are over five hundred yards from the shore and beyond Emerson's rocks. Wind storms and littoral currents are continually driving the sand and finer sediment southward along the shore of the island into Ipswich bay and down Plum Island river into Plum Island sound. Offshore ridges are then formed, on which the sea breaks, and the undertow then drives the sand and sediment shoreward upon Ipswich beach and Castle Neck. (See Fig. 29.)

At the northern end of Plum island and opposite the Joppa flats, as they run out from Woodbridge island, there is a pond called "the Basin," which was formed by the Merrimac and its tidal waters, by cutting into the sandy shores of the island while running out through the narrow channel. The opening into "the Basin" is dammed across by a looped bar which at low tide produces the pond.

Ipswich beach is situated on the shore of Ipswich bay between Plum island and the north shores of Gloucester and Rockport, and is formed by an indenture of the coast-line caused by the cutting away and removal by streams and sea wave-action of sedimentary beds of slate and sandstone. (See Fig. 31.) Remnants of these bed-rocks may be seen on the shore at "the Loaf," which is at the northern end of Coffin's beach, West Gloucester (see Figs. 33, 34), at Conomo point, Essex, and on the old Ipswich and Essex road.

The water in the Ipswich bay is shallow, the bottom for over a mile offshore being bare at low tide except for the narrow and ever changing ship channel leading to Plum Island sound and Ipswich river. This channel is deep, and the sand and sediment which are being moved southward along the coast are dropped to the bottom of the channel and there remain, for at that depth there is not sufficient agitation to move them. But the supply of drift-sand brought to this point does not cease, and the natural result is the accumulation of a sand-ridge in the channel which causes it to move to one side or the other as the current cuts a new pas-

sage with the least possible friction. This accounts for the well-known shifting of this channel. The United States Coast Survey Chart, No. 108, shows such a shifting of this channel between July, 1883, and July, 1884. This sand-ridge follows the boundary between the deep water near the channel and forms a spit with a lagoon shoreward. At the northern end of the beach, at a point opposite Steep hill, such a spit was built up during the seasons of 1900–1902, which extended southerly over a mile in a line parallel with the beach and about three hundred yards from the shore. A southeasterly storm forced backward the sand which was drifting down the spit and carried the end of it toward the shore, thereby forming a true sand-bar. A northeasterly storm then demolished both the bar and the sand-spit, and the sand and other sediment filled the lagoon shoreward, thus extending the beach to an outer sand-ridge or spit and nearly to deep water. (See Fig. 30.) Observations covering a series of years seem to prove that during the summer months the littoral and tide currents build up ridges of sand and drift on the shallow bottom parallel with the beach, so that in a favorable season there may be three or more ridges or spits of sand built up with lagoons behind them. The littoral currents transport sediments composed of sand, mud, and silt, which build up the spits and bars, and as the proportions of these component parts vary, so varies, in all gradations, the surface of the spit and the resulting beach, from hard and compact, to light and porous. Many forms of corrosion, erosion, and stream adjustment may be found here during a season to illustrate these forms in detail, as well as examples of spits, bars, ridges, cuspated forelands, lagoons, etc.

Sand-Dunes. — Plum island is covered with sand-dunes and drift-sands that are continually being moved southward into Ipswich bay by the prevailing high winds from the northwest and northeast. Occasionally a succession of heavy easterly gales will uncover the drumlins at the Ipswich end of the island, known as "the Jackman farm," in another season, to be covered again by the ever-drifting sand from the northern part of the island. This wind-blown drift-sand is washed upon the beach by incoming tide-waters, there to form the spits, bars, and ridges of Ipswich beach and Castle Neck. During the winter season northeasterly gales and high tides drive into Ipswich bay with great violence and, forcing the sands upon the beach, level and destroy existing forms of ridges, spits, and bars. Occasionally heavy northeasterly gales of several days duration, will churn the whole bay into breakers reaching out from the shore, line upon line, for a distance of two miles or

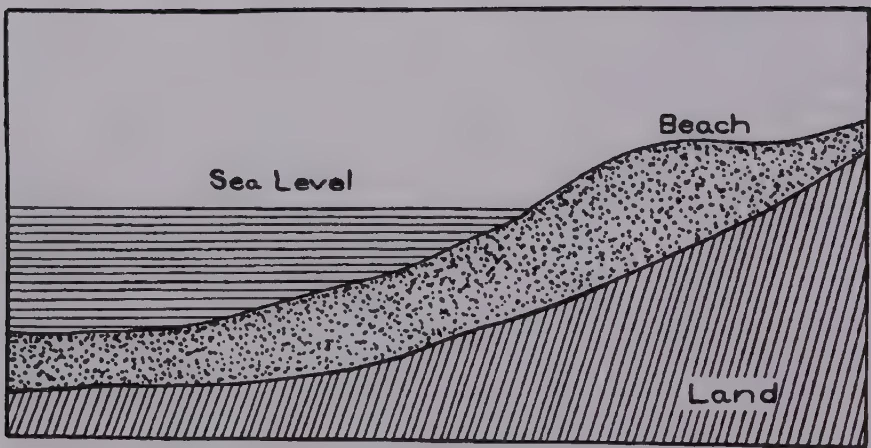


Fig. 28.—IDEAL SECTION OF A SEA BEACH, OF WHICH PLUM ISLAND BEACH IS A TYPE.

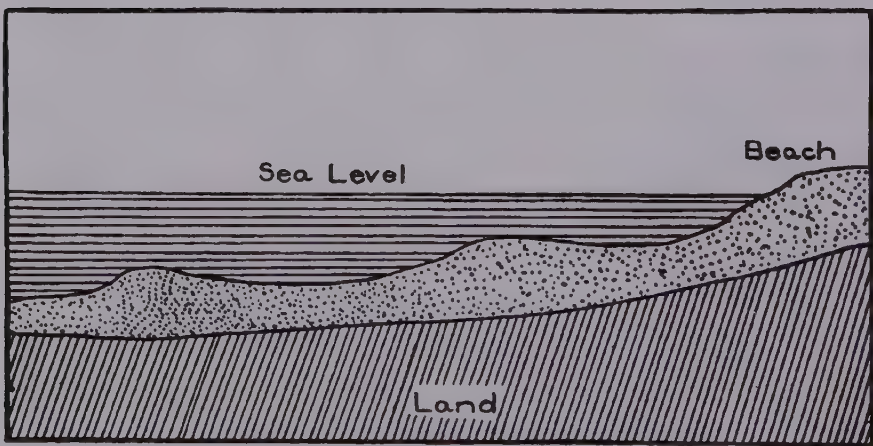


Fig. 29.—IDEAL SECTION OF IPSWICH BEACH.

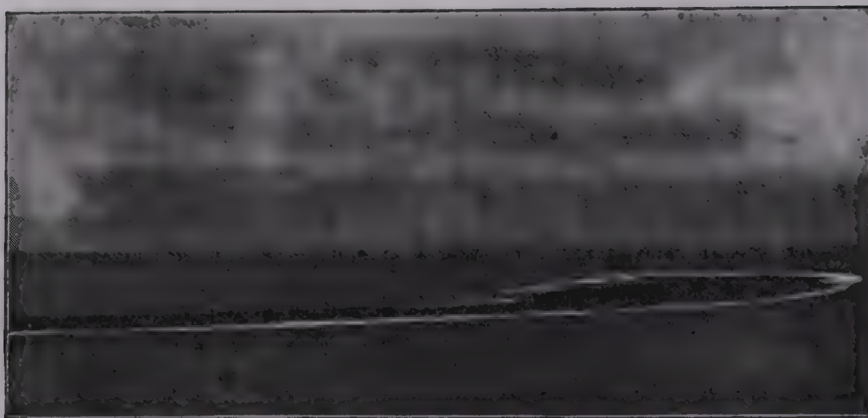


Fig. 30.—THE OFFSHORE BAR AT IPSWICH BEACH.
Showing cuspated foreland and lagoon.

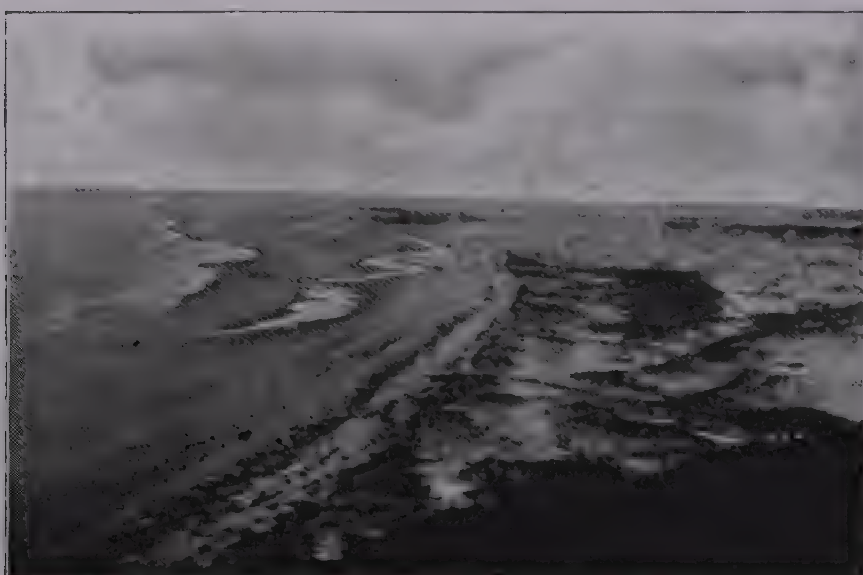


Fig. 31.—IPSWICH BEACH FROM THE TOP OF CASTLE HILL.
Showing cuspated foreland and offshore bar.

more. The undertow from these breakers dislodges from the bottom of the bay enormous masses of sand and other sediment which are driven high upon the beach by incoming tides. Sometimes a heavy gale will drive the wet sand over Castle Neck five hundred yards above the beach. Sand thus driven upon the high lands soon dries and is then blown before the wind and forms sand-dunes. (See Fig. 35.) Rarely is there a south wind of sufficient force to drive much of this sand northward into the bay, and therefore its tendency is to accumulate and to be blown southward. The shore currents also move it southward. The spit reaching out from the southeastern part of Castle Neck shows the effect produced. The steep bank of the ship channel leading into the mouth of Essex river is cut through a delta of this wind-blown sand. At Ipswich beach the sands encroach upon the farm lands and orchards (see Fig. 37), and the dunes even cover the drumlins at Castle Neck, southeast of which lies the Lakeman farm, which has been entirely covered by sand and the attendant sand-dunes. (See Figs. 36, 38, 39, 42.)

In 1898–9, the prevailing northwesterly winds drove the sand-dunes down to the end of Castle Neck opposite the entrance of Castle river, where new banks were formed forty feet in height which extended nearly to the Beacon ledge at the mouth of Castle river. Since 1901, all of this great mass of sand has been removed by high tides and northeasterly gales, so that now the Beacon ledge is two hundred yards from the nearest sand-dunes. These northeasterly gales drive the sand from Castle Neck southward to Coffin's beach and inland at West Gloucester. A large amount of sand from Plum island is also carried up the Ipswich river by the strong tidal currents and deposited on its banks in the vicinity of Fox creek where, for over a century, vessels have been loaded with sand to be used for building purposes without visibly decreasing the amount deposited at this point.

Shore dunes of considerable number occur near Coffin's beach, West Gloucester (see Fig. 34), and on the North Shore from near Halibut point to Annisquam. The latter are grassed over, showing that they are due to conditions not in operation at the present time. Subsidence of the land on these rocky shores causes very deep water so that only small amounts of sand are scoured up from the rocks and deposited on the shores. On the mainland of West Gloucester, opposite Annisquam village, there are very extensive dunes which are in active operation, moving farther inland each year (see Figs. 40, 41), and several tracts of tillage land have been overwhelmed. Dunes now cover woodlands in this region to a depth of

eight to fifteen feet, the sand having been deposited within the past thirty years. Drift-sand also occurs at Rockport in the valley occupied by Cape Pond brook, near the Boston and Maine railroad. Here, also, it is wind-blown and forms small dunes which are now fast disappearing as the sand is blown into the brook and carried away. These sands were probably deposited by the brook in times of flood.

Erosion of the Shore by Wave-Action. — The north shore of Gloucester from Squam lighthouse to Halibut point, Rockport, is bold and rocky, and fringes of granite and dike-rock ledges are exposed for nearly the entire distance. In a small bay back of Davis' Neck, at Bay View, sediments of sand and mud are deposited, and also at Folly cove, Lanesville, and at Plum Cove beach. These sediments are clearly derived from till which partially covers the granite ledges. Sandy Bay, Rockport, is a deep indentation in the coast-line formed on a line of weakness at a contact of the hornblende granite and the augite syenite rock formations. At the deepest part of the bay, the incurving shore receives the larger portion of the sediments produced by wave-action in cutting down headlands. On the eastern side of Cape Ann, from Emerson's point to Cape Hedge, there is now a cobblestone beach. The sand that covered this beach in 1893, has been dragged into deep water, carried southward, and deposited on Long beach, at Gloucester, from thence to be washed along the shore, for at the present time there is less sand upon this beach than appeared a few years ago. The same may be said of the beach between Brier Neck and Bass Rocks, at East Gloucester. Singing Sand beach or Old Town beach, at Manchester, is also wasting away. The beach derives its name from the rasping sound produced by the sand when it is walked upon. This sand is peculiar to this beach and the sound is caused by hard mineral surfaces rubbing against other projecting surfaces. A microscopical study of sections of this sand has demonstrated that a portion of the grains have rutile needles in and through the quartz and standing out beyond the surface. In one section these rutile crystals were found to radiate like the spokes of a wheel. Zircon crystals are also present in the feldspars. As the rutile and zircon crystals are harder and tougher than the feldspars, the grinding together of these grains produces the sound which gives its name to the beach.

Opposite the Ipswich end of Plum island and between Ipswich river and Green's creek are the drumlins known as Jeffrey's Neck. Between the North ridge and Plover hill, the sea has cut a small bay at the mouth of which a sand-bar has formed, damming the opening into the bay and

Fig. 32.—VIEW FROM GALE'S POINT, MANCHESTER, AT LOW TIDE.
Showing the following islands: House, Misery, Ram, Baker's, Eagle, and Lowell.

Fig. 33.—COFFIN'S BEACH, WEST GLOUCESTER, FROM BLACK ROCKS TO THE LOAF.
Showing ripple marks and cuspated drifting of sand. Ipswich beach and Plum island in the distance.

Fig. 34. — COFFIN'S BEACH, WEST GLOUCESTER.
Showing sand-dunes and Post-Pleistocene or Quaternary drift sand.

Fig. 35. — POST-PLEISTOCENE WIND-BLOWN SAND-DUNE AT CASTLE NECK, IPSWICH.
Showing stratification of the sand.

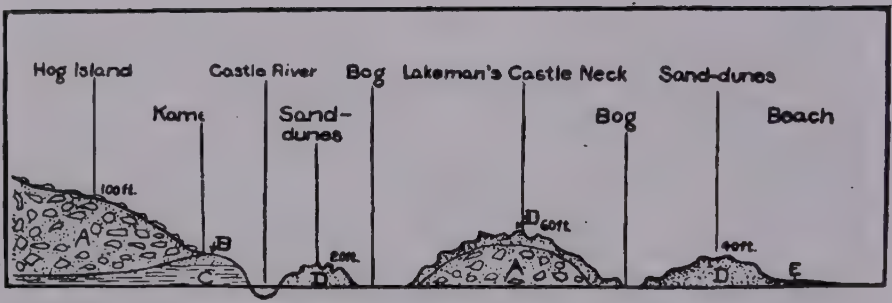


Fig. 36. — IDEAL CROSS-SECTION FROM HOG ISLAND, ESSEX, TO IPSWICH BEACH.
A. Drumlin. B. Kame gravel. C. Clay. D. Sand-dunes. E. Ipswich Beach.

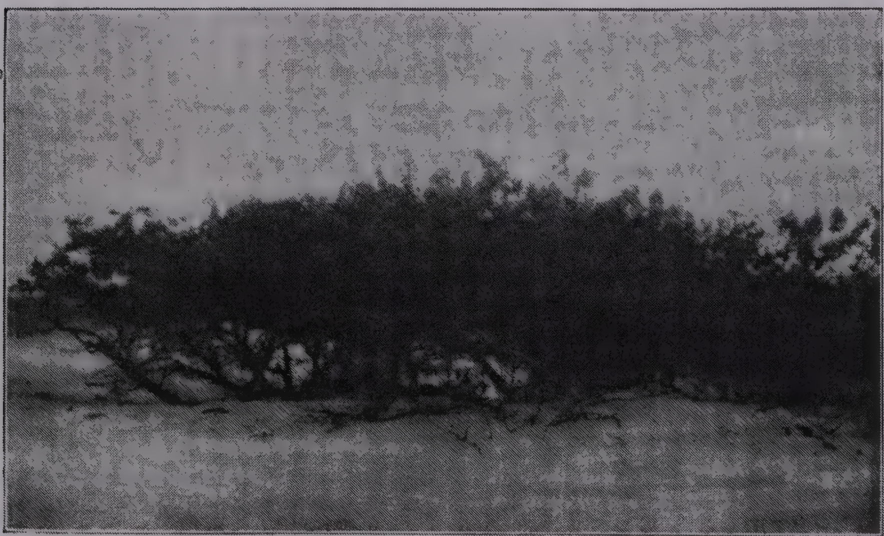


Fig. 37. — POST-PLEISTOCENE WIND-BLOWN SAND OVERWHELMING AN APPLE ORCHARD.
On the Lakeman farm, Castle Neck, Ipswich.

making what is now known as Clark's pond. A similar bar unites Great Neck and Little Neck at Ipswich. Davis' Neck is connected with Bay View, Gloucester, by a sand-bar, and a sand- and cobblestone-bar at Brace's cove, East Gloucester, encloses Niles pond. Forty years ago, Graves' island was connected with the mainland at Manchester, but subsidence and high tides have cut the bar and it has now entirely disappeared. Incipient bars have formed in the comparatively smooth water on the westerly side of Eagle, Coney, and Misery islands, in Salem harbor, and a few years ago Great Misery was connected with Little Misery by such a sand-bar, but in 1901 the sea had cut a deep-water channel between the islands. Marblehead Neck is tied to the mainland by a sand and cobblestone beach (see Fig. 43), and Nahant is connected with Little Nahant by a curved sand-bar, and beyond, with the mainland at Lynn, by a sand-bar that is over a mile in length. A small bar at Pond beach, Bass Point, Nahant, encloses Bear pond. The long bar connecting Little Nahant with Lynn and all similar bars are called "tombolas," by Italian geologists.[1]

Nearly all of these bars would be swept away by the sea but for the work of man in repairing the waste. The sea has frequently cut a passage through the bar connecting Marblehead Neck with the mainland, and the beach if not repaired would soon open up a channel and cause Marblehead Neck to become an island. The same is true of Nahant beach bar.

[1] See F. P. Gulliver, Proceedings of A. A. A. Science, 1899.

CHAPTER III

OUTCROPS OF BED-ROCK

NEARLY one half of the bed-rock of Essex County is distinctly stratified, and by means of our knowledge of these groups the geologic age of all the other rock-masses may be approximated. The term "stratified rock" is applied to different rock-formations in which stratification is the only common character, and although the syenites, diorites, felsites, and some of the breccias show stratification in part, there is little difficulty in separating them from the limestones, quartzites, and argillaceous rocks.

Stratified Rocks of Sedimentary Origin. — The sedimentary rocks of the County are nearly all of the Olenellus Lower Cambrian age, and are divided into several groups: the slates, sandstones, limestones, and the quartzites, all of detrital origin and to be classed as more or less metamorphic.

Metamorphism is here used in a broad sense as indicating the production of new minerals or new structures, or both, in pre-existing rock-masses. An excellent example of thermal metamorphism, due to the intrusion of volcanic rhyolite rocks, may be seen on the Breakheart Hill farm in Saugus. The slates here must have contained a considerable amount of carbonaceous matter, probably due to animal remains, which, when brought into contact with the great heat of the intruding rhyolites, were transformed into graphite and produced the knotted-schists or *knottinschieffer* of this area. These slates are in part brecciated by the intrusion of veins and masses of the rhyolite rock, and in some parts of the slate-beds the metamorphism assumes the type of flaky-schists, with all the varying gradations between knotted and flaky forms. The slates and sandstones on Marblehead Neck have been metamorphosed by the intrusion of veins and masses of hornblende granite, diabase dikes, and felsitic porhyries. The carbonaceous matter has been transformed into garnets, and the slates and sandstones have been changed into beds of quartzite and mica-schist. At Nahant the Cambrian slates have become

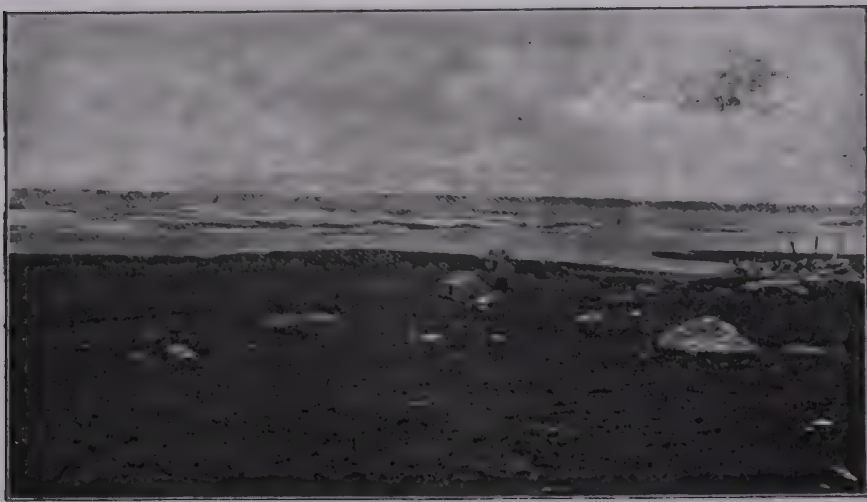


Fig. 38. — SAND SPIT OFF CASTLE NECK, IPSWICH.
As seen from Hog island, looking across Castle river.

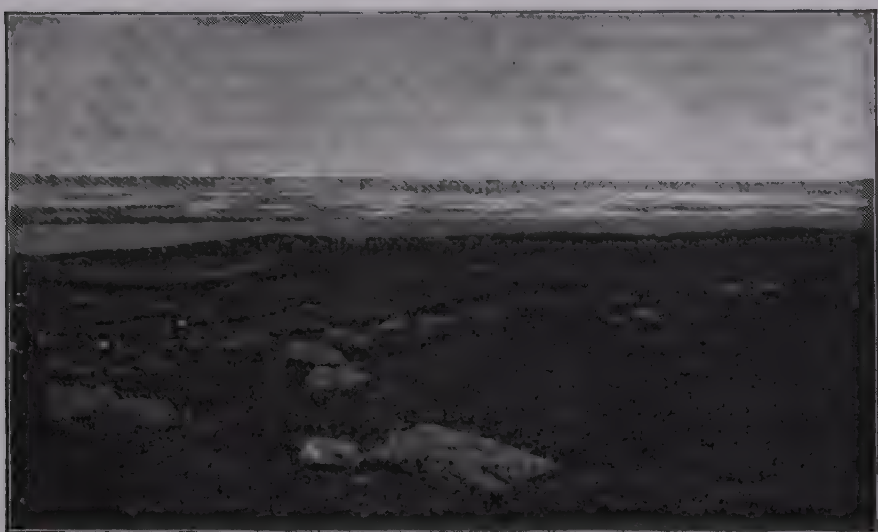


Fig. 39. — CONTINUATION OF THE SAND SPIT OFF CASTLE NECK, IPSWICH.
As seen from Hog island. Glacial drift boulders appear in the foreground.

Fig. 40. — SAND-DUNES ON A ROCKY HEADLAND NEAR COFFIN'S BEACH.
West Gloucester.

Fig. 41. — SAND-DUNES SOUTH OF COFFIN'S BEACH.
West Gloucester.

Fig. 42. — KAME RIDGE ON SOUTH BANK OF CASTLE RIVER.
North of Hog island, Essex. Ipswich lighthouse and Plum island in the distance at the left.

Fig. 43. — BARRIER BEACH BETWEEN CLIFTON AND MARBLEHEAD NECK.
(July, 1905) showing sea-worn pebbles washed into windrows by the tides.

calcined into a form of lydite, and andalusite has been developed in the folia or bedding-planes.

Cambrian Rocks. — The Cambrian rocks of Essex County are small remnants of a series of folds which must have been at least 10,000 feet in thickness. These remnants are now seen at Pickering's point, South Salem, on the shore at a point northeast of Fort Pickering; at Naugus head on the Marblehead side of Salem harbor; and northwesterly across Beverly harbor at the base of Goat hill. As the inclination or dip of these strata of Cambrian rocks is constant, it being about 40° southeast, the distance in a straight line across the upturned remnants, from Naugus head on the Marblehead shore to the outcrop at the base of Goat hill in Beverly, is about 10,000 feet. These beds probably were continuous across the area now known as Salem and Beverly harbors, and formed a fold at least 10,000 feet in thickness, covering not only Salem and Beverly but the whole of Essex County. During the Cambrian period there were mountains of these strata over the igneous eruptive granites and diorites. A demonstration of the above conclusion was shown at the time an artesian well was sunk on the property of the Salem Electric Lighting Company, on Peabody street, Salem. This well was bored to a depth of four hundred feet through nepheline syenite and diabase dike rocks. A sufficient supply of water not having been reached, it was decided to explode a heavy charge of dynamite at the bottom of the well. The explosion brought to the surface pieces of Cambrian limestone, one containing fragments of *Hyolithes*. By the accompanying diagram (see Fig. 44) it will be seen that this well is about 5,400 feet from Naugus head. A similar diagram carrying these strata to the outcrop at the foot of Goat hill in Beverly, would demonstrate the strata to be at least 10,000 feet in thickness.

Half-tide rock and Jeggles' island, in the southwestern part of Salem harbor, are small masses of the harder diorite rock which cut through the Cambrian slates. Half-tide rock has a vein of syenite cutting through it. The harbor itself is carved out of the softer Cambrian rocks, especially those near the contact of the igneous eruptive rocks. At such contacts invariably there is deeper water than elsewhere in the harbor.

At Jeffrey's ledge, about twenty miles east-northeast from Cape Ann, a deposit of Cambrian rock has been located, containing numerous fossils of *Hyolithes* and *Stenotheca*, and thereby this outcrop may be connected with the Olnellus Cambrian deposits of Nahant. Other outcrops of these crystalline Cambrian sediments have been found in various parts of the

County. One at Rowley, chiefly in the valley between Hunslow hill and Long hill but occasionally rising to an elevation of one hundred feet, is composed of a series of schistose argillite shales, ferruginous sandstones, and a cherty limestone which is much metamorphosed in bands of light and dark color. Microscopical examination shows this limestone to be composed of plainly stratified sediments of calcite, quartz grains, epidote, chlorite, some magnetite and limonite, and to be of the same character as that at Mill cove, North Weymouth. The fossils found at this outcrop, which can be identified, are all in the cherty limestone. The strike of this deposit is 20° north of east to southwest, dip 40° west, which is nearly parallel to the strike of the Olenellus Cambrian deposit at Nahant head. Another outcrop of these Cambrian rocks is found at Topsfield and is composed of the same succession of schistose argillite shales, ferruginous sandstone, and a cherty limestone that is near lydite. Other outcrops have been found at Archelaus hill in West Newbury, at an elevation of nearly two hundred feet; in red argillite shales in the bed of the Merrimac river; at Ward's hill in Bradford; and on the high hills of Methuen, at an elevation of one hundred feet.

The inference to be drawn in explanation of the presence of these Cambrian deposits scattered over the County is, that during the Cambrian period there was a vast sheet of these sediments deposited over the entire region to the depth of some hundreds of feet; but the great amount of denudation from various causes, particularly through the agency of the ice-sheet which covered this region during the Glacial period, together with the frequent faulting of the strata, makes it nearly impossible to give the exact depth of these beds. They have been distorted and crumpled into anticlinal and synclinal folds accompanied by, and perhaps casually connected with, the intrusion of the granite, diorite, syenite, and felsite eruptive rocks. The elæolite-syenite of Naugus head, on the Marblehead shore, and at Woodbury's point, on the Beverly shore, are seen to cut these sediments, and being also later cut by gabbros and quartz felsites, the contact metamorphism is so complete that the old crystalline sediments are now found as mica-schists. The diorite areas of Marblehead proper, Salem, Danvers, and Ipswich often contain fragments and masses of these metamorphosed crystalline sediments. At Danvers Centre a granitic gneiss is found. In Putnamville and Wenham the entire area is amphibolite schist or foliated hornblende diorite. Mining shafts and trenches for water-mains have opened these rock-masses in several places, showing the actual contact. In digging a well at Tapleyville, Danvers,

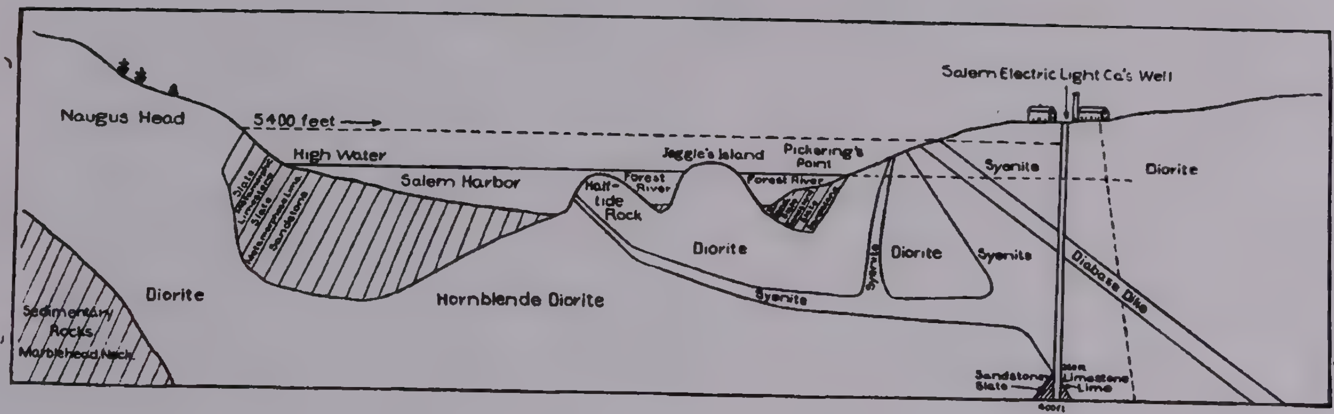


Fig. 44. — IDEAL VERTICAL SECTION ACROSS SALEM HARBOR SHOWING EXISTING STRATA OF CAMBRIAN ROCKS.

Fig. 45. — HORNBLENDE EPIDOTE GNEISS CUT BY A COARSE HORNBLENDE GRANITE.
Crooked pond, Boxford.

Fig. 46. — INCLUSION OF HORNBLENDE EPIDOTE GNEISS IN FOLIATED QUARTZ HORNBLENDE DIORITE.
A narrow vein of the diorite cuts through the gneiss upon which the watch is resting. Southeast of Crooked pond, Boxford.

on the bank of Tapley's brook, a bed of typical argillaceous shale was revealed. This brook occupies the valley between the granite areas of Peabody on the south, and the main mass of the diorite on the west and north, and the contact of these eruptive rocks with the crystalline sediments is probably so distant that the metamorphism in them is less complete.

In the eruptive dome-shaped bosses of the hornblende granite areas of Saugus, Lynnfield, Peabody, Manchester, and Cape Ann, there are numerous fragments and masses of these metamorphosed crystalline sediments. At Saugus on the east, and at Lynnfield on the west, of the granite there are extensive outcrops which are seen to be interstratified with layers of quartzite and mica-schist. This mica-schist is identical, macroscopically and microscopically, with the metamorphosed argillites of Nahant and Flying point, Marblehead Neck. The strike of all these beds is northeast to southwest, varying only a few degrees either to the north or east, thus showing that the intrusion of the eruptive magma was parallel to the foliation of the sedimentary beds. On Cape Ann there are numerous masses and fragments of the metamorphosed sediments in the hornblende granite. One large mass, near the Loaf, a rocky point on the northern end of Coffin's beach, West Gloucester, is several rods in extent and the foliation shows the strike to be northeast to southwest. This outcrop is below the high-water line and therefore the dip cannot well be made out. Another outcrop near Halibut point on the east side of Cape Ann, is of the same type and has the same strike, with the dip 40° west, parallel to the Cambrian beds at Rowley and Nahant. The position of these two metamorphosed crystalline sedimentary beds signifies that they are remnants of an anticlinal fold of the Cambrian sediments, perhaps produced by the intrusion of the eruptive granite magma from beneath them. It is not unreasonable to presume that the granite magma melted and enclosed large masses and fragments of these old Cambrian sediments, metamorphosing them into hornblende and mica-schist. This theory will also explain the presence of several gneissic fragments found in the granite quarries. Such a mass in the Trumbull quarry at West Gloucester, is twenty feet in length and tapers to a point near the surface of the dome-shaped granite boss. The enormous force exerted by the intrusion of the granite magma from beneath upon these Cambrian beds must have distorted them and left their entire surface a series of faults, cracks, and crevices, thus exposing them to all the various forces of erosion and decay. The work of the ice-sheet during the Glacial period must

necessarily have been upon these sedimentary beds, scouring and grinding them to rounded boulders and to fine till, which were deposited all over Cape Ann and in the waters of the Atlantic. One of these stratified boulders on Ten Pound island, in Gloucester harbor, and another on Thatcher's island, are typical examples of the larger of these fragments, while in Whale cove there are great numbers of all sizes and of every shape. This theory would also account for the absence of glacial grooves and striæ on much of the surface of the granite areas, for probably the ice-sheet never touched the larger portion of the granite. Aërial decay has since destroyed all that was left of these sedimentary beds after the ice period, except such remnants as are found to-day.

A large number of thin sections from all the outcrops, when studied with the microscope to determine the detrital character of these stratified beds, have invariably sustained the determinations made in the field.

Hornblende Epidote Gneiss. — This is an ancient rock-mass, and probably the oldest member of the Archean series represented in Essex County. The granitic quartz hornblende diorite, which is the principal formation in the Crooked pond area at Boxford, and which occurs in both massive and foliated forms, cuts through the hornblende epidote gneiss. Veins of granite also cut both of these rocks in various directions. (See Fig. 45.) Nearly half a mile south from the above outcrop, are numerous blocks of this gneiss as inclusions in the foliated and massive quartz hornblende diorite. (See Fig. 46.) The hornblende epidote gneiss is therefore shown to be an older formation than the quartz diorite, and it is also demonstrated that the flow of the quartz hornblende diorite magma, which picked up the blocks of this gneiss, was from the north in a southerly course, as there are no outcrops of the gneiss south of the included blocks. A short distance southwesterly from Crooked pond is an outcrop of this rock in the form of a conglomerate, a breccia cut by forms of the quartz hornblende diorite. Dynamic metamorphism has greatly altered the minerals in this rock, which has been pressed and crushed between a massive amygdaloidal melaphyre dike on the east and the quartz hornblende diorite on the west. In consequence, the augite is nearly all replaced by green hornblende which the crushing force exerted was sufficient to thoroughly metamorphose. The original brown hornblende is replaced by biotite and the soda-lime feldspars, and the soda-bearing silicates are separated in the form of crystals of albite, while the lime-bearing silicates, in conjunction with other constituents of the rock, aid in forming

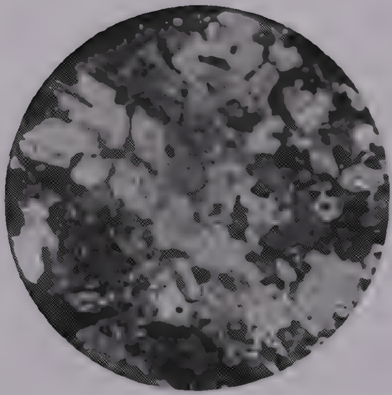


Fig. 47.—PHOTOMICROGRAPH OF HORNBLENDE EPIDOTE GNEISS.
Crooked pond, Boxford.

Fig. 48.—CAVE IN LEDGE OF QUARTZ HORNBLENDE DIORITE.
East of Crooked pond, Boxford.

the minerals rich in lime, such as epidote, zoisite, and calcite. These minerals form narrow elongated lenses, some of which are three or four inches long and give the metamorphosed rock-mass a distinctly gneissic appearance, suggesting to some geologists the name — stratified diorite. A later phase of the metamorphism of this rock is the crushed and broken crystals of secondary feldspar, which may be seen near the contact of the aplitic granite veins, which cut through this entire series of melaphyre, quartz diorite, and hornblende epidote gneiss. North of Crooked pond this gneiss has been quarried for building purposes. Southwest of the quarry there is an outcrop of this rock in the form of a conglomerate of rounded pebbles, which becomes a breccia still further in the same direction.

South of Woodchuck hill, on the north side of Boston brook, there is an outcrop of the hornblende epidote gneiss with a strike northeast to southwest. Continuing in this course about two miles, the rock again appears on the Jenkins farm in Andover. Northeast from the first outcrop, it is also seen south of Fish brook, near the North Andover and Boxford town lines. South of Kimball and Sawyer's mill-pond in Boxford, a series of outcrops extend nearly to Four Mile pond, and west of the first-named pond a gneissic quartz diorite is found. On both sides of the outlet to Stiles' pond, and on either side of Spofford's pond, are outcrops of hornblende epidote gneiss. Southwest of Rock pond in Georgetown, there are three outcrops.

On the bank of Mill river, at Dodge's mill, Rowley, this formation appears, and in a northeasterly direction there are numerous outcrops. Two hundred yards southwest from the Mill river outcrops, a blue limestone appears, beyond which is another outcrop of the gneiss, and then an outcrop of foliated quartz hornblende diorite.

On the south side of Uptack hill in Groveland and extending eastward to "Federal City," are several outcrops of hornblende epidote gneiss, which reach southward and appear on both sides of Rock pond in Georgetown. Half a mile north of Bald Pate pond is another outcrop in a railroad cutting, and at the southeastern base of Long hill, at "Rooty Plain," are two other outcrops between which appear blue limestone and quartzite. The strike of the whole series is north 40° east, the dip varying from 30° north of west to 90°.

Following the strike of the hornblende epidote gneisses across Essex County, there are outcrops in various places near Foster's pond, Andover, and on the roadside, in a cutting near the John Jenkins farm, there is an

exceptionally good exposure where this gneiss is seen for several rods with the same strike and with the dip slightly to the west. Numerous exposures are also seen in Farnhamville, North Andover, and on the Lacy farm on the road to East Boxford.

Hornblende epidote gneiss from Crooked pond (see Fig. 47); section across the bedding, microscopic structure: green hornblende; twinned feldspar with numerous inclusions of quartz grains; patches of quartz in which there are numerous fluid inclusions; large patches of zoisite, biotite, and magnetite; numerous areas of chlorite and epidote. Section parallel to the bedding shows the zoisite surrounding hornblende crystals and the hornblende in turn surrounding grains of magnetite, all lying in one plane across the section dependent upon one plane of pressure. Titanic iron surrounded with leucoxene is abundant in this section.

A section across the bedding of a specimen of metamorphic hornblende epidote gneiss from the John Jenkins farm, Andover, gave brown hornblende allied to green hornblende; magnetite; plagioclase with numerous inclusions of quartz; biotite flakes, and masses in the plane of bedding; numerous quartz grains, many of them well-rounded and containing numerous fluid inclusions; some patches of chlorite; numerous grains of epidote; a little sahalite, and large masses of zoisite.

Ancient Rocks of Sedimentary Origin on Cape Ann. — The principal and largest mass of this sedimentary rock is seen on the shore at the westerly side of Folly point, east of Langford's cove, at Lanesville. This outcrop varies in width from ten to thirty feet. The strike is north 40° east to southwest. The length of the outcrop, exposed between low water and the covering of drift on the hillside, is about one hundred yards.

The microscopic structure is: well-rounded grains of quartz and feldspar, scales of biotite, some titanite, garnets with irregular outline, and some magnetite. The larger feldspars have inclusions of muscovite, quartz, and epidote, and are surrounded by chlorite. This rock is clearly a mica-schist, metamorphosed from a sandstone.

Another outcrop of this mica-schist, which is interbedded with a granitic gneiss and chert, is seen in an abandoned quarry in the Bay View region. It has the same dip and strike as the outcrop at Lanesville. This gneiss has the same microscopic character as the gneiss of Boxford and Andover, and further investigation will undoubtedly show that this rock belongs to the lower Cambrian sediments, thus placing in this group the so-called Archæan-gneiss found in the large tract in the northern part of the County.

On both sides of Brace's cove, Eastern point, Gloucester, is a clearly metamorphosed sedimentary rock of irregular outline and of considerable

Fig. 49. — MERRIMAC RIVER FLOWING UNDER THE CHAIN BRIDGE AT NEWBURYPORT.
Quartz diorite rock on both sides of the river.

Fig. 50. — CAMBRIAN SLATY SANDSTONE LEDGE AT SOUTH LAWRENCE.
Used (1901) for road material.

extent, with a strike north and south to northeast and dip nearly vertical, and which is also seen as inclusions in the hornblende granite of the region.

The microscopic structure is : rounded, and irregular grains of quartz and feldspars cemented in a ground-mass of chlorite and limonite.

Another extensive outcrop is seen at Essex, in the valley between White and Powder House hills, and extending across Essex to Conomo point. Here, the slates, which are distinctly interbedded with gneiss and quartzite, are in places filled with garnets varying from microscopic size to one fourth of an inch in diameter. These slates therefore have been metamorphosed into garnetiferous-gneiss, a form not before noticed in Essex County rocks, except in boulders on Cape Ann and Nahant. As the two regions last named are in direct line with the variations of the glacial striæ on the surface of the rocks throughout the County, it may be presumed that these isolated boulders are remnants of glacial material originating in this outcrop in Essex.

Opposite Magnolia, on the western side of Kettle cove, is a bedded series of arkose conglomerates, indicating that some earlier form of granite has been reduced to gravel and reconsolidated.

A bed of ancient sediments also outcrops on the harbor on the western side of Misery island, and extends nearly to the northwestern point, a distance of 294 yards. These bedded rocks are known as *schiefferhornfels*, and were so named by Professor Rosenbusch of the University of Heidelberg. The rock is produced from the decomposition of a diabase tufa, and contains augite in grains and stringy pieces, which is contrary to the theory of a sedimentary rock. In the photomicrograph (see Fig. 51) the augite is shown in the black color in ragged lines.

Slate or Mica-Schist. — These rock-masses are usually interstratified with sandstone, and the schist is undoubtedly a metamorphosed slate. Nearly all of the bed-rock of West Newbury, Groveland, Haverhill, Lawrence, and Methuen is composed of this metamorphic slate.

The outcrops north of the granite area in South Lawrence and West Andover, and extending into Salem, N. H., are a metamorphosed slate and sandstone, now transformed into a hard mica-schist, the strike of which is northeast to southwest, varying from 10° north of east to northeast. Near the gneissic granite quarries of the Essex Company in South Lawrence, these slates in part are less metamorphosed, and are simply phillite slates much crumpled and sheared and showing considerable regional distortion, due to lateral pressure by the intrusion of an olivin

basalt or dike rock. Near the contact of the slate and one of these dikes the former is full of vesicles — a typical scoria. At a contact with the dike and the granitic gneiss, the latter is calcined and baked to a hard bluish-grey rock. Within three hundred yards of the granite quarries before mentioned, and in a northwesterly direction, the mica-schists and less metamorphosed slates form an outcrop by the roadside. The bedding of the slate shows very distinctly but is somewhat crumpled, owing to the veins of granite which cut through the rock. The strike is northeast to southwest and the dip is nearly vertical.

The microscopic structure of the metamorphic slate, in the bed of the Merrimac river, below the Lawrence dam is: clastic grains of quartz sand; some secondary quartz surrounded with earthy yellowish kaolin and chlorite masses; titaniferous magnetite and leucoxene; and a few grains of plagioclase with inclusions of apatite, zircons, and fibrolite. The quartz grains show evidence of crushing, embryonic cracks are developed, and some of the grains are broken and the pieces faulted two, and in one instance three times.

On Canal street, South Lawrence, southwesterly from the dam across the Merrimac river, there is an outcrop of Cambrian slate and another may be seen near the corner of Crosby street.

Other outcrops of slate occur on both sides of the river road and extend nearly to the West Andover crossroad, north of Fish brook. Toward the west the outcrops near the Dracut town line are more slaty, showing less metamorphism. One outcrop near Bartlett's brook is a typical argillite slate, and similar outcrops may be found at the south and east of Harris' pond in Methuen and elsewhere in the town. Near the state line, and on both sides of the Spicket river, the slate is interstratified with sandstone. North of the village of Methuen there are large outcropping ledges of the slates which have been used for road building. The original formation has been greatly changed to a very hard blue schist, by the intrusion of massive dikes of granite and diabase. Between Bear Meadow brook and Lone Tree hill, on the west side of Methuen, there is an outcrop of slate and sandstone with a strike north 20° east; south 20° west. Fragments of *Hyolithes* fossils and casts of annelids are frequently found in these slates. Fragments of *Hyolithes* are also abundant in the city ledge at South Lawrence where the slate is interstratified with a fine sandstone containing calcite. (See Fig. 50.)

Nearly all of the bed-rock of Methuen is composed of this metamorphic slate and a coarse mica-schist, of the same composition as that from Law-

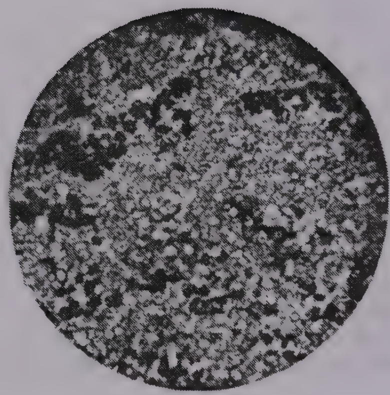


Fig. 51. — PHOTOMICROGRAPH OF SCHIEFFERHORNFELS.
West cove, Misery island.

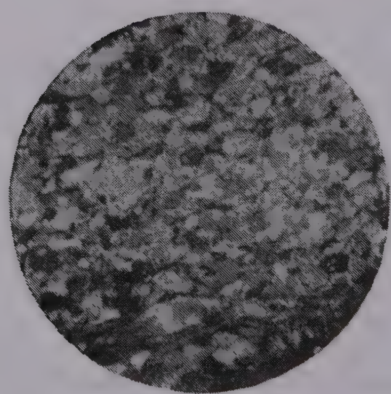


Fig. 52. — PHOTOMICROGRAPH OF QUARTZITE SANDSTONE.
South Georgetown.

rence, Haverhill, and Gage's hill in Bradford. In Methuen, this slate and schist formation is over one thousand feet in thickness, and its trend is north 40° east-southwest; dip 45° west. Nearly every outcrop from West Andover across Lawrence, Methuen, Bradford, Haverhill, Merrimac, South Hampton, Hampton Falls, and North Hampton, to Rye, in this strike, is composed of these same metamorphic slates and schists.

At Andover, the Shawsheen river cuts its channel through Cambrian red limestone and slate, a fact which was clearly shown in 1899, when the foundation was laid for the new dam of the Stevens Woolen Mills.

In Merrimac, there are only two outcrops of bed-rock, one, south of Cobbler's brook on the river road, and the other, in a cutting made by the electric railway. They are both slaty mica-schists, a metamorphosed form of slate and sandstone. On the southern side of the Merrimac river these slaty sandstones also make their appearance and form the bank of the river extending from the Artichoke river westerly across West Newbury and Groveland. Large outcrops also appear near Pipe Stave hill, Archelaus hill, and west of Indian hill.

A crumpled metamorphic slate found in West Newbury, north of the First Congregational church, is greatly decomposed on the surface of the outcrop. It has a strike north 10° east, to south 10° west. The dip is nearly vertical, being slightly west.

The microscopical structure shows quartz grains with fluid inclusions of carbonic acid, much muscovite, and muscovite interlaminated and cemented with ferrous oxides and limonite. Many of the quartz grains show incipient cracks, while some of them are broken and crushed or faulted. The feldspars, by decomposition, have produced kaolins and earthy chlorite.

At Bradford, Little Niagara brook cuts its course through slate and sandstone and has a steep waterfall, suggesting the name applied to the brook. At Mitchell's falls, north of Kimball's island, in the Merrimac river, the Cambrian slates metamorphosed into hard mica-schists with veins of calcite, turn the course of the river towards the north and around Ward hill, a massive outcrop of this mica-schist. At the southeast of the hill the rock outcrops and is seen for three hundred yards in a cutting made for the railroad.

The microscopical structure of this metamorphic slate shows angular and rounded grains of quartz in abundance, with a few grains of feldspar, muscovite, biotite, and chlorite, developed in the plane of cleavage of the rock-mass. Titanite, with its decomposition product, leucoxene, is seen in parts of the section. Rutile

and magnetite occur in the chlorite areas. The larger quartz grains are filled with fluid inclusions and show incipient cracks in all stages. Some sections of these slates found in the northern part of Methuen on the bank of the Spicket river, are so completely metamorphosed that little else can be recognized than quartz and an earthy kaolin with titaniferous magnetite. The metamorphism is so complete that single grains of quartz are often seen broken and faulted two or three times.

South of the Ward Hill railroad station the road bed cuts through a massive basalt dike, at a contact of the metamorphic slate with the coarse mica hornblende granite of North Andover. From Ayer's Village, Haverhill, towards the north and northeast and extending into Atkinson, N.H., are numerous outcrops of slate and sandstone, cut parallel to the bedding of the slate and intersected by veins of granitic gneiss containing veins of pegmatite. North of Crystal lake, Haverhill, wherever the outcrop of granitic gneiss becomes massive it has large blocks of slate taken up by the gneiss in the flow of the magma, previous to its consolidation, and thereby showing this gneiss to be an intrusive eruptive rock.

Veins and dike-like masses of this granite cut through the slate-beds or mica-schists of Methuen and Lawrence. An outcrop is found southeast of Ayer's hill in Methuen, and another occurs west of Bear Meadow brook, where both slate and granitic gneiss appear. Several outcrops formerly existing in Lawrence, within the city limits, are now concealed by buildings, among others, one between Appleton and Jackson streets, another at Court place, and a third, at the corner of Brook street, near the Spicket river.

The microscopical structure of a metamorphic slate from the Cannon hill area in Groveland, shows many detrited grains of quartz, angular and well-rounded; a little secondary quartz; rounded grains of orthoclase largely kaolinized; earthy biotite, abundant in long flat crystal forms in the plane of the schistosity of the slate; a few plates of muscovite; titaniferous magnetite with leucoxene; rutile in needle-shaped crystals to be seen in some chlorite masses. Some of the quartz grains are crushed and broken by the pressure which caused the metamorphism of these beds.

North of the Merrimac river, opposite the town of Groveland, the slaty sandstones cut by veins of granite come to the surface, appearing on the west side of Kenoza lake, at Riverside, and southeast of Corliss hill. At Riverside, on Groveland street, there is an outcrop of a highly metamorphosed slaty rock, cut by veins of granitic gneiss. In 1890, a stone-crusher was installed here to reduce the ledge for road-building material. One mass of the rock was found to be a very basic eruptive,

Fig. 53.—CAMBRIAN LIMESTONE AND CHERT.
East Point, Nahant.

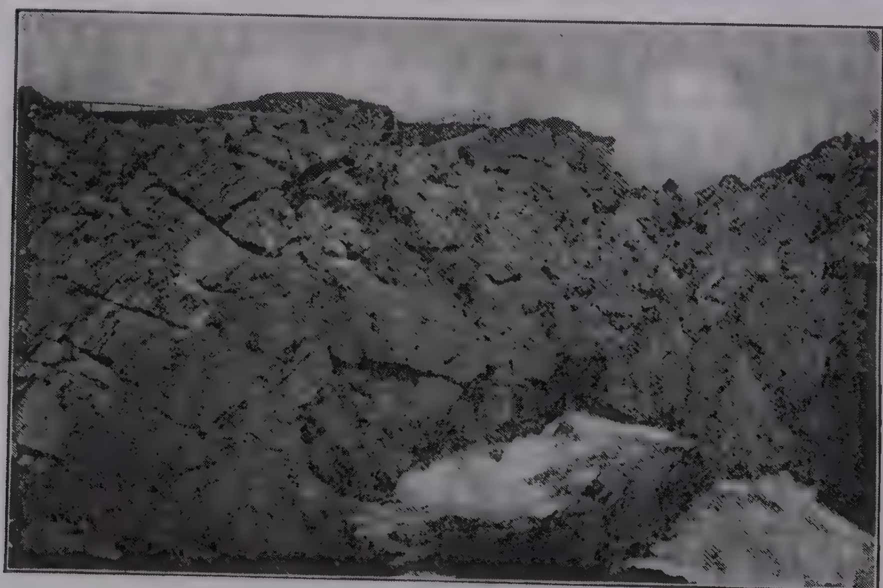


Fig. 54.—CAMBRIAN LIMESTONE AND CHERT CUT BY A MASSIVE BASALT DIKE.
North of Pulpit rock, East point, Nahant.

penetrating and metamorphosing the slate to a sericite-schist in which the sericite penetrated plates of biotite crosswise to the basal cleavage. Probably this rock was originally a sericite phyllite.

The microscopic structure of a metamorphic slate from East Haverhill, as shown by five sections, is: angular and rounded grains of quartz in some of which are numerous fluid inclusions; several quartz grains in the line of the schisosity of the rock-mass, showing cracks from all the incipient stages to the broken and crushed masses; feldspar grains much kaolinized and showing the effect of crushing, some of the grains being broken into several pieces; scales of muscovite and biotite arranged in layers parallel to the schistosity of the rock-mass; and inclusions of apatite, zircons, fibrolite, and rutile abundant in the kaolinized feldspars. Titaniferous magnetite and leucoxene are scattered through the sections, and fine acute rhombs and long lath-shaped sections of titanite are seen in one of the thin sections.

In the roadway east and south of Archelaus hill, West Newbury, outcrops of red limestone and slate occur containing fossil *Hyolithes*. These beds also outcrop on Prospect street, Bridge street, Bailey's lane, and on the bank of the Merrimac, north of Long hill. At the base of Brake hill, West Newbury, there is an outcrop on both sides of the road, extending for over 1,000 yards. Here the slate and sandstone are interstratified and the slate is greatly sheared and very fissle. On Pleasant street, an old quarry shows similar forms, many blocks of the slate having a crumpled appearance. These Cambrian sedimentary rocks here occupy an area of about nine square miles.

An intrusive granite protogine gneiss, cutting remnants of sedimentary beds of shale and sandstone in the bed of the Merrimac, is found one eighth of a mile west of the Chain bridge at Newburyport. This gneiss shows that the minerals of the intrusive rock and also the shaly slate have been greatly metamorphosed.

The microscopical structure shows that a large proportion of this rock is composed of rounded grains of quartz, some grains of orthoclase and plagioclase, muscovite, and garnet with magnetite and limonite. The feldspar grains are filled with inclusions of quartz and muscovite, as a micrographic structure. Some larger plates of muscovite have numerous inclusions of zircons, which show fine pleochroic halos as the stage of the microscope is revolved 90°, the halos appearing and disappearing. The garnets are crushed and broken, showing that they have been subjected to great pressure and strain.

The shaly slate shows numerous quartz grains having incipient cracks and broken grains, with numerous inclusions of zircons and garnets. There are also larger lenses of secondary silica in the line of cleavage. Some grains of orthoclase

appear badly decomposed. Earthy kaolin, chlorite, epidote, titanite, and some leucoxene appear, and muscovite, biotite, and titanite grains are arranged in the plane of cleavage of the slate.

On Kent's island in Newbury, at the junction of Little and Parker rivers, there is a bed of argillite interstratified with sandstone, which extends about one thousand yards on the bank of the Parker river to a point near the railroad, and on Little river one hundred yards west. Some of the beds are of a dull red color, resembling the North Attleboro and North Weymouth slates, while others are of a greenish color. They are cut in several directions and are distorted by felsites and amygdaloidal melaphyres, shearing and faulting to such an extent that the true bedding is quite difficult to determine. By uncovering the glaciated surface, however, and washing away the clay and drift, the bedding is plainly revealed. The strike is 50° north of east; dip 55° southwest.

The microscopic structure of a very opaque section of the red slate, cut across the bedding is: clastic quartz grains and fragments, showing secondary enlargement and crushing and containing numerous fluid inclusions, surrounded by a ground-mass of earthy kaolin; much muscovite and ferruginous magnetite and limonite. The sections of the green slate from Little river are composed of angular and rounded quartz grains; a finely fibrous kaolinized ground-mass; some epidote, muscovite, a few grains of zoisite, and much chlorite. The alternating sandstone is composed of quartz and feldspar grains, some biotite and scales of muscovite, and much ferritic oxide.

Several outcrops of Middle-Cambrian sedimentary rocks, blue limestones, blue and red slates, and quartzite, appear south of the Ipswich river in Topsfield. Fossil *Hyolithes*, *Stenotheca*, a fossil resembling a minute sponge, a fossil coral, and numerous casts of annelids have been found in thin sections of the blue limestone. These Cambrian rocks are cut by hornblende diorite and are intimately associated with an ancient arkose conglomerate granite which occurs in the immediate region of the slate. In fact the slate seems to have surrounded the arkose, but an exact contact does not occur. On the Pike farm, a large outcrop of chert or metamorphosed limestone appears. On Cross street, near the "Donation Farm," the arkose granite occurs in the form of a massive ferruginous arkose of Pre-Cambrian age. Other outcrops appear on the summit of Price's hill and in the "sugar loaf" hills about the village. Five of these "sugar loaf" hills have been opened, and all are arkose covered with a thin coating of drift, sand, and gravel. It is a typical conglomerate granite, con-

Fig. 55. — HORNBLENDE DIORITE LEDGE ON THE PICKMAN ESTATE.
South Salem.

Fig. 56. — HORNBLENDE DIORITE LEDGE IN PROCESS OF REMOVAL BY THE MASSACHUSETTS BROKEN STONE COMPANY, 1898. CASTLE HILL, SALEM.

taining pebbles of a ferruginous limestone and coarse mica-schist, surrounded by pebbles and masses of the arkose. The presence of such a large body of this arkose indicates that the area was formerly an ancient land created long before the formation of the Lower Cambrian sediments.

South of the village of Topsfield, by the side of High street, there are outcrops of Cambrian slates, and a small hill on the western side of Perkins street is largely composed of Cambrian limestone. On the Clark farm, about two miles from this hill, are several outcrops of Cambrian quartzite, slates, and cherty limestones, and continuing in this northeasterly direction, other outcrops may be seen by the roadside near the base of Little Turner's hill in Ipswich.

At West Boxford, the hill between the forks of the roads leading to Bradford and Groveland, is largely a sedimentary slate and cherty limestone, and this outcrop is also nearly continuous on both sides of the Uptack hill road in Groveland and Georgetown. South of the Lakeside farm, a western extension of Uptack hill having an elevation of 220 feet above mean sea-level is almost entirely composed of a cherty limestone and slate.

The microscopical structure of the metamorphic slate from the area extending from Johnson's pond, West Boxford, to the north of Chadwick's pond, shows numerous sub-angular and rounded grains of quartz ; rounded and broken grains of orthoclase and albite ; plates of biotite and muscovite ; some cordierite, chlorite, earthy kaolin, and limonite. The cement is formed by the earthy kaolin and limonite.

On both sides of Little pond, West Boxford, are outcrops of sedimentary beds which resemble hornblende epidote gneiss, but upon close examination are seen to be Cambrian sedimentary rocks. Towards the southeast from Little pond, where prospectors have blasted for silver, the rock is a blue limestone and chert. A mile to the north, where the road crosses a brook, an inlet to Johnson's pond, outcrops of slate and sandstone occur in the bed of the brook. On the bank of the mill pond in Groveland, near the electric railway, is another outcrop of these sedimentary rocks. The road from West Boxford to South Groveland winds upward through the Cambrian sedimentary rocks, and at the highest point there is a wide vein of fine micaceous granite, a very handsome rock. These vein-granites also outcrop on the top of the hill at the Washington street cutting, and on the same street there is a massive dike of hypersthene diallage gabbro, in places fifteen feet wide, which cuts all

the other members of this series of granites, together with the sedimentary beds and the hornblende epidote gneiss as well.

Red Shank hill, in South Georgetown, is a large outcrop of ferruginous slate and schist of sedimentary origin. This rock also appears in the cellar of the Town Hall at Georgetown. Nubbly hill and Nelson's hill are both outcrops of a quartzite having a strike northwest to southeast or directly opposite from the strike of other outcrops in this area, with one exception — Red Shank hill, on which a massive dike has cut halfway to the top and forced a portion of the sedimentary beds from the southeast around to the northwest.

Between Nelson street, South Georgetown, and Perley's pond, Boxford, there is an outcrop of slate-sandstone and quartzite (see Fig. 52) in which a cutting, twenty feet deep, was made a few years ago while prospecting for gold. At a contact of the sandstone and gneissic hornblende diorite, a vein of grey copper was exposed.

North of the old "lime-pits," near Steven's pond in Boxford, there are outcrops of slate, sandstone, and quartzite.

The microscopical structure of a ferruginous metamorphic slate from Chaplinville, Rowley, taken from between Hunslow hill and Prospect hill, is as follows: angular and rounded grains of quartz; feldspar grains with some small plates of muscovite and biotite; small crystalline plates of calcite, cemented together with an iron oxide, probably limonite. Most of the muscovite plates are arranged in lines parallel to the bedding. The quartz and feldspar grains show perfect outlines and do not exhibit the broken and crushed appearance seen in more metamorphic slates, especially near the granite and quartz diorite areas.

The Cambrian outcrops of quartzite and slate at Lynnfield Centre were studied in 1898, when a well was opened in the cellar of a house owned by H. B. Nesbit. The dip was 35° west and the strike north and south. At the bottom of the well, twenty-eight feet below the surface, the slate contained much graphite. Above the slate-beds was found white limestone interstratified with a light blue slate and quartzite. Although no fossils were discovered, the lithological character of the rock and the form of the beds indicated an Olenellus Lower Cambrian sedimentary rock.

The microscopic structure of a quartzite from Lynnfield Centre is: quartz grains containing numerous fluid inclusions and incipient cracks; also crushed and broken grains produced by pressure in the rock-mass during metamorphism; much secondary quartz, which, with the polariscope, gives the usual wavy extinctions; some

Fig. 57.—HORNBLENDE DIORITE OUTCROP.
In the "Nubble Squid," Groveland.

Fig. 58.—SPLIT BOULDER OF HORNBLENDE DIORITE.
Near the "Nubble Squid," Groveland.

grains of secondary glassy plagioclase; perfectly fresh grains of microcline; orthoclase kaolinized and much decomposed, with numerous inclusions of zircons and apatite crystals; some chlorite, and a little biotite. An outcrop at this point is exposed for a distance of one hundred yards and is in some places finely schistose and laminated, while in others it is massive. The strike is north 20° east; dip 50° west.

On the eastern side of Breakheart hill, in Saugus, between the base of the hill and Saugus river, are several outcrops of Cambrian slates and metamorphosed limestones in contact with aporhyolites. At this contact the slates have become metamorphosed into a knotted-schist, or *knottinschieffer*, and in some places a typical *flickinschieffer* has resulted in all gradations, from the typical slate to the knotted and variously blotched forms of these schists. Higher up the hill the quartzite becomes a quartzite-conglomerate in various forms, from fine gravel-like pebbles to a coarse gravel in which all of the pebbles are quartzite, with a quartz cement holding them together and forming a very hard tough rock. A boulder of this quartzite-conglomerate, weighing several tons, may be seen (1904) on the Lynn harbor side of Little Nahant. Without doubt this boulder was detached from the ledge on Breakheart hill and rafted across Lynn harbor during the Glacial period.

At North Saugus, near the corner of Main and Oak streets, there is an outcrop of metamorphic slate interstratified with a quartzite, and on Main street, two hundred yards east of the school-house, the hornblendic eruptive granite cuts directly across this metamorphic slate and includes large fragments. The strike of these metamorphic slates and quartzites is north 20° east, and parallel to that of similar beds at Lynnfield Centre.

The microscopic structure of this metamorphic slate is: clastic quartz grains with many fluid inclusions; well-rounded grains of plagioclase; orthoclase almost entirely decomposed; biotite; some muscovite, and magnetite; ground-mass, a ferruginous earthy kaolin with some fibrous chlorite, and a few grains of epidote. The quartzite from the same place in thin section shows: quartz grains with numerous fluid inclusions; feldspars much kaolinized and containing numerous inclusions of apatite, tourmaline, and epidote; while patches of chlorite are often seen in the line of the bedding. The whole rock-mass is thoroughly saturated with a ferruginous limonite, giving it a dirty yellowish color.

An outcrop of Cambrian slate at Crescent beach, Nahant, shows considerable metamorphism, and is the same as the slate found at Wyoma in Lynn. At the beach, the cleavage, which has been developed crosswise to the original bedding planes, is much wider than the secondary

cleavage planes in the rock at Wyoma and is filled with andalusite, showing the fine pink color of that mineral.

The microscopical structure of this metamorphic slate shows quartz grains of a detrital character with evidences of crushing. Incipient cracks across the grains are common in all sections of the rock. Orthoclase, deeply kaolinized in well-rounded grains appears; a few grains of albite; biotite, usually in layers in the line of the bedding of the slate, and numerous fine grains of magnetite appearing thickly through the minerals in all parts of the section. A secondary cleavage crosswise to the bedding has been developed and is filled with a slightly pleochroic reddish-pink to white andalusite. Grains of epidote and epidote crystals are seen in the feldspar grains. Fluid inclusions, in which the bubble movement is quite active, appear in some of the quartz grains.

A short distance north of Bennett's head, Nahant, there is exposed at low tide a metamorphic slate having a strike northeast to southwest. It is again seen at Bass point in the southwest part of the town.

The microscopic structure of this slate in thin section is : grains of quartz ; some feldspar in bands, alternating with dark bands composed of grains of quartz; grains of magnetite in large amount; flakes of biotite; some flakes of chlorite ; muscovite; and a large number of grains of a slightly greenish tinge, giving, with the polariscope, quite high single refraction and often showing a rectangular prismatic outline; parallel extinction commonly giving an aggregate fibrous polarization. These grains may be andalusite decomposed to muscovite aggregates.

On the southeast side of Nahant head, dipping under the banded limestones, is a typical argellite slate.

A microscopic examination shows an abundance of muscovite ; numerous quartz grains with fluid and microlithic inclusions, some of the quartz grains showing the incipient cracks and partings due to crushing ; well-rounded grains of plagioclase, probably derived from some gneissic formation, with quartz and numerous microlithic inclusions. The ground-mass is composed of earthy kaolin and fibrous chlorite and embedded in it are numerous cubical iron pyrite crystals.

This slate is again seen on the north side of Little Nahant, where it is interstratified with a coarse mica-schist containing much quartz, some of which is of clastic origin and still shows the grains of original quartz sand.

On both sides of Little Nahant, the outcrops of slate and sandstone contain numerous fossil *Hyolithes*. Pea island, south of East point, is a massive outcrop of quartz hornblende gabbro. The Shag rocks are cherty limestone and slate. (See Fig. 54.) From East point to Bennett's head, the Olenellus Cambrian slate-chert and limestone is cut by numerous

Fig. 59. — DEVIL'S DEN, NEWBURY, SHOWING LIMESTONE AND SERPENTINE IN THE FOREGROUND.

Fig. 60. — DEVIL'S DEN, NEWBURY, SHOWING A QUARTZ HORNBLENDE DIORITE FORMATION.

basic dikes, one of which is an olivin basalt. (See Fig. 53.) This limestone contains numerous fossil *Hyolithes*, *Stenotheca*, brachiopods, etc. The nearest bed of metamorphic sedimentary rock is the outcrop near Flying point, Marblehead Neck. This rock-mass is now a mica-schist metamorphosed from slate, and is cut and greatly distorted by the eruptive granite.

The microscopic structure of this rock-mass as shown by several thin sections is as follows: several grains of microcline well twinned with numerous inclusions of micro-zircons; orthoclase much kaolinized and earthy; quartz in angular and rounded grains, some crushed and broken and many showing incipient cracks due, no doubt, to local metamorphism; much muscovite and biotite lying in the plane of the schistosity; a few grains of epidote; fragments of white garnets, and numerous large patches of red garnets which are much broken and crushed, and an abundance of magnetite and some limonite.

The disintegration of this rock produces the magnetite and garnet sand of the region. Thin sections of the rock in a road-cutting at the north of the Atlantic House on Marblehead Neck, exhibit a typical quartzite. The mica-schist of Naugus head, Marblehead, and Woodbury's point, Beverly, probably belong to this metamorphic slate although the metamorphism is more complete; for, in these last-named outcrops, the schist is not only cut by the granite but it is also cut by the diorite, elæolite zircon syenite, felsite, and diabase dikes, thus making the metamorphism of the rock-mass most intricate; indeed, as pointed out by Dr. M. E. Wadsworth, the elæolite zircon syenite has been injected in large sheets into these schists, in the planes of the schistosity and jointings of this rock, to such an extent that in some places it is puzzling to decide which is syenite and which is metamorphosed slate.

Microscopical examination shows this slate to be composed of a few grains of clastic quartz sand; much secondary quartz; secondary glassy feldspars; some muscovite; an abundance of biotite which is probably secondary; a few grains of epidote; apatite, as inclusions in the ground-mass which is feebly polarizing earthy kaolin; much magnetite, red garnets, and micro-zircons.

Sandstone. — In Andover, near Butterfield's sawmill, is an outcrop of metamorphic micaceous sandstone lying parallel to the hornblende schist on the east. This formation is again found at the John Jenkins farm near the crossroad to Ballardvale.

The microscopic structure of sections from these outcrops is: quartz grains of original sand cemented by a film of ferreous oxide and some secondary quartz,

scales of muscovite and biotite, and masses of fibrolite. One of the sections from the last-named outcrop is composed of quartz grains and angular fragments, with numerous fluid inclusions showing incipient cracks and broken grains, much muscovite, some biotite, magnetite, chlorite, and epidote.

Another large area of the metamorphic slate, interstratified with sandstone, first seen near a small pond in South Groveland, is nearly continuous from Johnson's pond in West Boxford to the north side of Chadwick's pond in Bradford, and forms all the adjoining outcrops for nearly two miles in North Andover.

The microscopic structure shown by several sections is : well-rounded original grains of quartz and plagioclase; biotite; muscovite; a little chlorite cemented by a thin film of secondary quartz and ferreous oxide. One of the sections contains magnetite and limonite. The sandstone is composed of nearly pure quartz sand, cemented by some secondary quartz and a fibrous feebly polarizing feldspathic mass ; fluid inclusions in which the bubble movement is quite active are frequent in the quartz grains.

In Middleton, half a mile southeast of the village, near the house of Mr. J. U. Parker, is a well-preserved clastic shale approaching a sandstone. This outcrop shows a strike nearly northeast to southwest with the dip 50° north of west. It is again seen in an outcrop in the rear or west side of the barn of Mr. Francis Peabody, near the Ipswich river on the north side of the village.

The microscopic structure of this shale is: angular and rounded grains of quartz which show embryonic cracks and much crushing, and in some grains a secondary enlargement; plagioclase twinned feldspars, broken and crushed, some of which are in well-rounded grains; ground-mass, an earthy kaolin with plates of biotite; some muscovite; and an abundance of magnetite in the planes of the schistosity of the shale. Fine inclusions of micro-zircons are seen in the kaolinized feldspars. Some of the dark opaque patches resemble lignite, and it is not impossible that this shale is carboniferous, although it requires more field work and lithological study to prove it.

In the line of the strike to the northeast, across the Ipswich river in Topsfield and on the land of Mr. Peterson, two hundred yards northwest of the old Endicott copper mine, this shale, which is here a dull red color, protrudes in several places. It is interstratified with a ferruginous sandstone, the strike remaining constant — northeast to southwest with the dip 50° west.

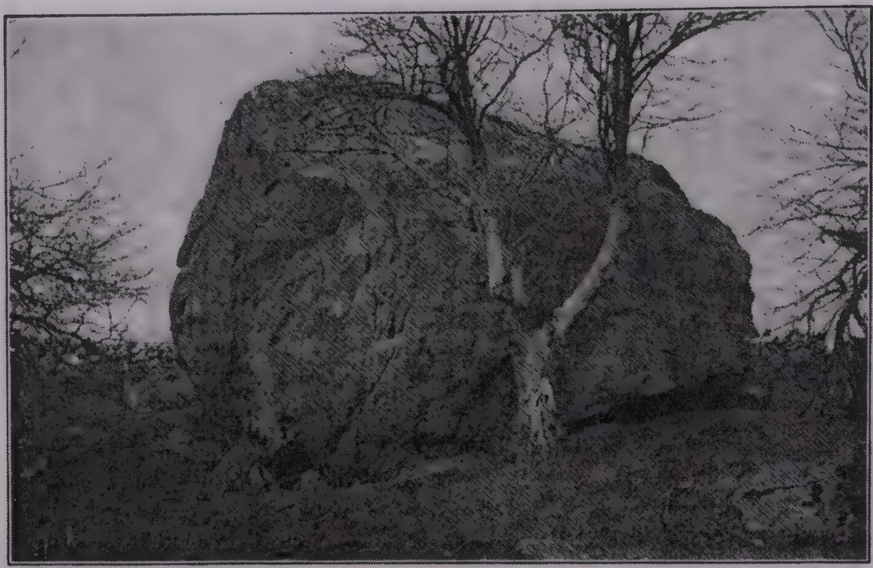


Fig. 61.—STICKNEY BOULDER, GROVELAND.
A hornblende diorite rock resting upon an outcropping ledge of hornblende diorite

Fig. 62.—SPLIT BOULDER OF HORNBLENDE DIORITE, NEAR THE STICKNEY BOULDER, GROVELAND.

The microscopic structure of thin sections from the outcrop near the roadside is as follows: section cut across the bedding — ground-mass of earthy kaolin much discolored with a ferruginous iron oxide; magnetic titanic iron; some leucoxene; original quartz grains showing secondary enlargements, incipient cracks and broken grains and also fluid inclusions; some feldspars much decomposed; muscovite scales; green chlorite; apatite; numerous microliths and zircons; a few grains of zoisite and epidote. A strongly developed shearing to the north accounts for the crushed and broken appearance of the quartz and feldspar grains. A section across the bedding from a specimen of the outcrop in the field on the opposite side of the road, near the dwelling-house of Mr. Peterson shows: ground-mass composed of earthy kaolin and fibrous chlorite; magnetite; titaniferous iron surrounded by leucoxene; micro-zircons; apatite; numerous microliths so small that they cannot be determined with the highest power of the microscope; quartz grains with numerous fluid inclusions; muscovite; and a few grains of zoisite arranged parallel to the bedding. Another section of ferruginous sandstone from Peterson's land in Topsfield shows: ground-mass of quartz and feldspar grains; numerous flakes of muscovite with detrital angular fragments and pebbles of the quartz; feldspars colored with ferreous oxide; some epidote and chlorite and threads of calcite.

Continuing on the strike of this shale, there are two outcrops in the northeastern part of Topsfield, one in Linebrook, a parish of Ipswich on Bull brook, one in Rowley near John Dodge's mill, and another near tide-water between Ipswich village and Rowley. The microscopic structure of the sections, from specimens in the cabinet of the Peabody Academy of Science taken from these localities, is nearly the same as that of the last two from Topsfield. Other outcrops of these clastic shales are frequent in the northern part of the County. On the southern bank of the Merrimac near the Artichoke river, there is a large area of this shale much crumpled and distorted with the strike north and south and dip vertical. Near the point where Indian river empties into the Merrimac, the shales are continuous for three hundred yards, and from Bradford across North Andover and South Lawrence, in a southwest course, they can be traced in an almost unbroken line to West Andover. On this strike the shales are bedded between the granite gneisses on the south and the metamorphic slates on the north.

Limestone. — Among the most interesting of the stratified rocks are the Nahant limestones. They are first seen on the south side of Nahant head, at the Shag rocks, and extend about three hundred yards to a point just beyond Bennett's head on the north. These limestones are much metamorphosed into bands of light and dark lydite, microscopic sections of which reveal calcite, quartz grains, magnetite, and mica, with occasional masses of nearly pure calcite interstratified with an indurated silicious

slate. In thin sections, under the microscope, they are shown to be composed of calcite, epidote, quartz, serpentine, white garnets, and limonite; chlorite tinges portions of the rock green, while hematite and limonite turn other parts red, thus giving the mass a brightly banded appearance, its most striking feature to casual observers. By means of certain fossils which have been found in this rock the horizon of its formation is determined as the Olenellus Lower Cambrian. Mr. Auguste F. Foerste first described one of these fossils, *Hyolithes inæquilateralis*, sp. nov., in the Proceedings of the Boston Society of Natural History, Vol. 24, p. 262, and numerous specimens have since been collected from the region, together with *Hyolithes princeps*, *Hyolithes communis*, var. *Emmonsi*, *Hyolithes impar* and *Stenotheca rugosa*. The strike of this limestone is 18° north of east, the dip 40°–43° west.

In July, 1890, an outcrop of this Olenellus limestone was discovered in a valley between Prospect hill and Hunslow hill in Rowley. It has nearly all become altered to chert and epidote, but fragments of the *Hyolithes* are still to be found. This outcrop dips under a red sandstone, which in turn is covered with the fine-grained granitic gneiss of the region. The strike of this outcrop corresponds very nearly with that of the Nahant rock of a similar character, and is 20° north of east with a dip 45° west. A mass of diorite, known as Metcalf's rock, cuts across this limestone on the southeast near the Ipswich line, and on the north it is covered by the banded red felsites of Byfield.

Near Bennett's head, Nahant, the strike of this limestone is 20° west of north, dip 45° southeast. Here the limestone rock-mass has been turned or pushed one side by the intrusion of a massive dike of very unusual character, and which under the microscope in thin section is seen to be composed of hypersthene, olivin somewhat serpentinized, diallage, plagioclase, biotite, numerous brown zircons, magnetite, a little calcite, and brown hornblende.

In limestone the most common metasomatic change is dolomitization, the process by which calcite is converted into dolomite by the replacement of half of its lime by magnesia. Good examples of more or less perfectly dolomitized rocks occur in Newbury near the Devil's basin and in various other parts of the town.

Fig. 63. — NORSEMAN'S ROCK.
A quartz hornblende diorite outcrop in West Newbury.

Fig. 64. — CRADLE ROCK, GROVELAND.
A glacial perched boulder of diorite, resting upon an outcropping edge of diorite.

CHAPTER IV

THE ERUPTIVE PLUTONIC ROCKS

Quartz Augite Diorite. — This formation has several distinct forms: quartz augite diorite, quartz hornblende diorite and a foliated form of the same type, quartz augite mica diorite with hornblende diorite, porphyritic diorite, and amphibolite. It has its greatest development in Newbury, Newburyport, and Salisbury, where it occupies an area of about 12,800 acres. In a southwesterly direction, extending through the towns of Georgetown, Boxford, Middleton, and Andover, the quartz hornblende diorite is the prevailing rock. The form, quartz augite diorite, which has been taken as the type, may be seen in all parts of both areas.

The numerous bed-rock outcrops by the roadside in the towns of Salisbury and Seabrook are quartz augite diorite, sometimes containing hornblende. Outcrops also occur at Pettingill's zinc mine, and several small outcrops extend to a point north of the Rocky Hill meeting-house. Eagle, Carr, Deer, and Ram islands in the Merrimac river are nearly bare ledges of this rock, which also occurs north of John True's house in Salisbury, with large veins of quartz in which black tourmaline crystals have been collected. Twenty-nine small outcrops of this rock appear on either side of the railroad in a distance of a little over a mile, and seven more appear west of Town creek. Crossing the Merrimac into Newburyport this quartz augite diorite was encountered nearly the whole length of Market street, in laying a sewer pipe.

On High street, at Belleville, Newburyport, there are ledges of this rock, and on the bank of the Merrimac opposite Carr's island, a similar ledge was quarried for stone to be used in building the jetties and breakwater at the mouth of the river. The abutments of the famous Chain bridge across the Merrimac at Deer island, are also built upon this quartz hornblende diorite rock. (See Fig. 49.)

The microscopical structure of this formation shows quartz, plagioclase, albite, Labradorite, orthoclase, augite hornblende epidote, calcite, calcite titanite, calcite apatite, and magnetite. Uralite has been formed from the decomposition of augite

biotite. Chlorite with calcite surround and are intimately associated with the hornblende areas as if they were decomposition products of the hornblende. The rock on the Salisbury side of the bridge is essentially the same.

Quartz augite diorite is found northwest of the Chain bridge and lying parallel to and enclosing a foliated mass of the same structure. It also is seen east of the bridge and opposite Carr's island on the Salisbury side.

The microscopical structure is as follows: quartz in coarse particles, numerous plagioclase feldspars, considerable calcite, some orthoclase, an abundance of chlorite, some biotite magnetite, limonite magnetite and pyrite, and numerous fine acicular crystals of rutile in the quartz and chlorite. Small zircons as inclusions in the biotite are abundant. Uralitization of augite into uralite and actinalite, with a core of augite, is common in many parts of the section.

A foliated quartz hornblende augite diorite found west of the Chain bridge, has the following microscopical structure:

Angular masses of quartz are abundant; some augite is seen and much green hornblende with broken and bent fragments of plagioclase, feldspar, biotite; some muscovite, magnetite, cubical iron pyrite, limonite, chlorite, calcite, and earthy kaolin in which there are numerous crystals of apatite. Green hornblende and angular fragments of quartz, broken and faulted, are arranged in the line of the flow of the rock-mass, suggesting that the rock has been subjected to great strain and pressure during its consolidation from the magma.

Thin sections of quartz hornblende diorite from the old quarry opposite Carr's island at Newburyport, and from Salisbury, give the following minerals:

Uralitized augite with occasional masses of typical augite; hornblende; biotite; plagioclase having the extinction angle of Labradorite; some orthoclase and quartz; an abundance of chlorite; considerable calcite of secondary origin; numerous crystals of apatite ; fine acicular crystals of rutile ; large micro-zircons ; iron pyrites, and magnetite.

South of Little river in Newbury, other outcrops occur and frequently appear near the Four Rock crossing of the railroad. Extending southward to the Parker river and including the silver mine region, it is the prevailing rock. South of the Newburyport turnpike, on the right-hand side of Highfield street, there are masses of dolomitic limestone and a talc, some of which is of very fine quality and is used locally in place of French chalk.

Fig. 65. — ORDWAY BOULDER, BYFIELD.
A glacial erratic of foliated quartz hornblende diorite.

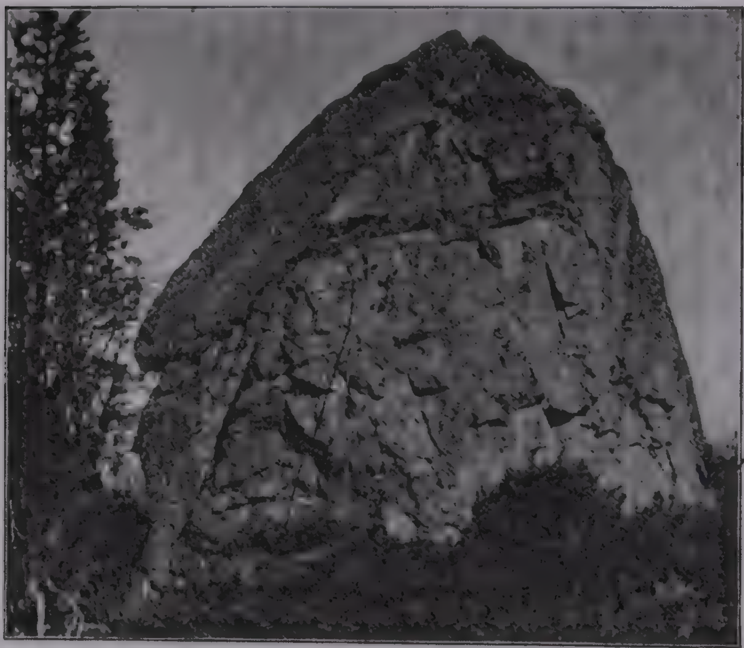


Fig. 66. — HAYSTACK BOULDER, NEWBURY.
A glacial erratic of quartz hornblende diorite, probably removed from the ledge six hundred feet distant towards the north. A ten-foot pole rests against the boulder.

Hornblende Diorite. — This is found in Groveland and extends southward across Georgetown and Boxford, where it becomes more or less foliated and contains considerable quartz. In either massive or foliated form it is the prevailing bed-rock in Boxford (see Fig. 69) and Middleton, and extends in a southwesterly direction across West Peabody and Lynnfield to Saugus, where it becomes quite granitic. Masses of the latter type are found in the northeastern part of Lynn and Swampscott, and in Marblehead. North from Swampscott in parts of Marblehead, Salem, and Peabody and across Danvers, the prevailing type is the hornblende diorite with little or no quartz. (See Figs. 55, 56.) There are also five distinct outcrops in the muscovite biotite granite area in Andover and North Andover. This rock formation is therefore about thirty-two miles long and averages about six miles in width. Its greatest width, twelve miles, is from North Andover across Boxford to Ipswich. In part of this area the rock-mass is distinctly an augite hornblende diorite. This is particularly well seen at Marblehead, near the old fort, and on Gerry's island. In Danvers and Beverly there are numerous small porphyritic and pegmatitic masses of this formation. At Putnamville, Danvers, foliation in these rocks has produced a form which has received the distinctive name of amphibolite gneiss.

East of Ilsley's hill, West Newbury, there is an outcrop of hornblende diorite, one half of a mile wide, with numerous angular fragments of the rock scattered over an area of one quarter of a mile square. One large boulder may be seen at the corner of Main and South streets. This diorite area extends into Newbury to a point about eight hundred feet west of the Byfield railroad station. Crane Neck hill, west of Ilsley's hill, is surrounded by outcrops of this diorite which extend into Groveland in this direction and form the well-known boldly outcropping ledges — the "Nubble squid." (See Figs. 57, 58.) Hornblende diorite also appears on Centre street, three quarters of a mile southwest from Cannon hill.

A foliated quartz diorite is the prevailing rock covering the area from Long hill in Georgetown and Rowley, to Byfield at a point east of the Lower Parish meeting-house, and thence towards Newburyport. South of Georgetown this rock extends to Pye brook in Boxford, where outcrops occur in the cemetery east of Stevens' pond and also on the grounds of the Second Corps of Cadets. An outcrop appears on the Rowley road within two hundred yards of the Boxford railroad station, and others occur nearly a mile away between the Rowley and Georgetown roads. In this area D. Frank Harriman sank a shaft for silver ore to a depth of

seventy-five feet, in which the rock was found to be a typical quartz hornblende diorite.

West of Hunslow hill in Rowley there is an outcrop of foliated gneissic quartz diorite of the same type as the outcrops at Long hill in Georgetown. A mile north of Chaplinville in Rowley, the Boston and Newburyport turnpike cuts through a hornblende diorite ledge, and a short distance to the northward there is a massive outcropping dike of aplitic granite. Northeast from this last outcrop, on both sides of Pasture brook, southwest of Ox Pasture hill, are outcrops of granodiorite — contacts of quartz hornblende diorite and aporhyolite — on the north of which is aplite or vein granite. Outcrops of a coarse felspathic diorite appear north of Jewett's hill and extend to Foss' Corner and Bean's Crossing. These outcrops are in part hornblende diorite running into quartz hornblende gneissic diorite.

The outcrop southwest from Ox Pasture hill by the roadside opposite Dole's Corner, is a coarsely crystalline rock, the microscopical structure of which shows large areas of multiple-twinned Labradorite, a little orthoclase, green and brown hornblende, some biotite and muscovite. Magnetite and chlorite quartz appear in the feldspars. Zonal structure is often seen in the Labradorite, and prismatic sections of the green hornblende extinguish at 8° to 10° oblique. High double refraction and fine twinning parallel to C is seen in the Labradorite, while apatite crystals are abundant as inclusions in the hornblende. Calcite and chlorite with magnetite surround areas which formerly were hornblende.

East of Hunslow hill, Rowley, is a series of massive outcrops of hornblende diorite known as "Metcalf rock," which extends southerly into Ipswich. This diorite rock is also seen at the southwest of Turkey hill and south of Bush and Scott's hills, near the Ipswich river. Main street, in the center of the village of Ipswich, is laid out over a ledge of diorite, with dikes of diabase, which extends nearly to Heartbreak hill. There are also outcrops of diorite on the southern banks of Rowley river and on the Ipswich poor-farm.

The outcrops of bed-rock over the entire region north of the aporhyolite area in Byfield are quartz hornblende diorite and hornblende slate with a few areas of typical hornblende diorite, which, near "the lime-pits," pass into an augite and diallage gabbro. Two hundred yards west of Cart creek, near the Copper mine opened by Luther Noyes and in a quartz augite diorite area, there is a massive outcrop which is probably a wide dike of diallage.

Fig. 67.—A GLACIAL ERRATIC BOULDER OF QUARTZ AUGITE DIORITE.
Located a short distance from the Haystack boulder, Newbury. Length, 28½ feet and width 18 feet. Upper surface is well glaciated. The nearest outcrop of this formation in the line of glaciation is in Amesbury.

Fig. 68.—FOLIATED GRANITE WITH INCLUSIONS OF QUARTZ DIORITE.
At the base of Long hill, Boxford.

The lime in the old lime-pits at "Devil's den," Newbury (see Fig. 60), is without doubt a secondary deposit formed from the decomposition of the augite and diallage. Microscopical sections in polarized light show it to be an augite diallage peridotite or pickrite, and not a sedimentary limestone. The green serpentine of these lime-pits is another stage in the metamorphism of the augite diallage rocks which must be classed as a pickrite peridotite.

The serpentine is usually massive and compact in texture, of a dark oil, olive, or blackish green color, though sometimes a pale yellowish green. It is also found in a fibrous and lamellar form called chrysotile, popularly known as asbestus. It is a metamorphosed igneous rock, occurring as massive dikes or bosses in the hornblende diorite or quartz hornblende diorite areas. (See Fig. 59.) A microscopical study of thin sections from the "Devil's den" and basin, in Newbury, shows it to be composed originally of augite diallage olivin and hornblende, probably an ancient basalt. The apparently pure white limestone (see Fig. 71) from this locality shows irregular patches of slightly yellowish green serpentine with the cleavage of hornblende. Outlines of augite crystals changed to serpentine are also seen. Olivin is sometimes present as a nucleus. Some sections contain olivin in which the nucleus is iron, and around the olivin there is a circle of serpentine. These changed minerals are known as pseudomorphs, having been derived from some other species by chemical change. The serpentine at South Lynnfield is also in the form of a massive dike cutting the hornblende diorite of the region. Here its color is a blackish green and in thin sections it shows good basal cleavage. Sections of hornblende, now turned to serpentine, prove this rock to be a serpentine hornblende pickrite. This rock probably extends for about one half of a mile in a northeasterly course, for a similar serpentine outcrops beside the road near Hersey's blacksmith shop in West Peabody. The biotite mica peridotite by the side of Skug river in Andover, is also an altered serpentinized olivin dike-rock. It is a rare form of rock and is found no where else in the County.

When studied from thin sections it is seen to be composed of biotite-mica which is bleached to a nearly white color, calcite, talc, serpentine, and magnetite surrounding irregular patches of olivin, which is rare, some tremolite and a few small masses of augite which are also surrounded by serpentine. (See Fig. 82.)

A chemical analysis of the serpentine from the "Devil's den," at Newbury, resulted as follows:

SiO_2	41.33
FeO	2.36
MgO	41.49
H_2O	14.54
	99.72

Vesuvianite occurs at Newbury in the old lime-pits known as the "Devil's den," where it is quite massive and somewhat crystalline. Thin sections, cut in the line of its optic axis, give exceedingly brilliant polarization colors with high double refraction; so also do sections parallel to the prism and parallel to the pyramid. The specific gravity is 3.60. The following analysis was made by James T. Greeley of the Massachusetts Institute of Technology.[1]

SiO_2	35.93
Al_2O_3	14.77
FeO	8.91
CaO	39.46
MgO	.13
K_2O	.44
Na_2O	.36
	100.00

Crane Neck hill, a large drumlin in West Newbury, is surrounded by outcrops of hornblende diorite which extend into Groveland and Georgetown. The rock at Groveland is a form of quartz hornblende diorite.

The well-known Stickney boulder near Centre street in Groveland (see Fig. 61), is a mass of hornblende diorite resting upon a bare ledge of the same rock. The base of this boulder is roughly rectangular and measures 27 feet by 18 feet. The height averages 14 feet and therefore gives 6,804 cubic feet of contents. The specific gravity is 3.375, and a cubic foot accordingly weighs 211 pounds, giving a total weight of about 718 tons.[2] In the immediate region are other large boulders known as Split rock (see Fig. 62), Cradle rock (see Fig. 64), and Norseman's rock, a large outcrop of quartz hornblende diorite (see Fig. 63).

In West Newbury, on the J. B. Little road, there is an outcropping ledge of diorite with veins of quartz. "Nubble squid" or "Knubble

[1] See Massachusetts Institute of Technology Quarterly, May, 1888.

[2] See Hitchcock's Geology of Massachusetts, page 373, where the weight of the rock is estimated to be about 2,310 tons.

Fig. 69.—MASSIVE AND FOLIATED QUARTZ HORNBLENDE DIORITE OUTCROP WITH INTRUSIONS OF COURSE VEIN-GRANITE.
Lovering's mountain, Boxford.

Fig. 70.—HORNBLENDE DIORITE AT LEDGE HILL PARK, SALEM.
Showing glaciated surface.

squid" — either name is of doubtful origin — is a large outcrop of hornblende diorite or trap-rock (see Fig. 57), in the southeastern part of Groveland, extending across West Newbury into Newbury and Georgetown. These hornblende diorite rocks have a tendency to run into the quartz diorite of Newbury to such an extent that they may be considered as parts of one and the same rock, although separate from the quartz augite diorites of the Newburyport, Salisbury, and Amesbury area. These hornblende diorites are thoroughly granitic in type, and but for the amounts of augite and plagioclase in some parts of the area, would be classed as a form of augite granite; in fact, some outcrops contain a large proportion of augite with little or no orthoclase. Uralite has replaced the augite, and calcite has been developed. All of the outcrops from Georgetown to West Newbury, on either side of the J. B. Little road and as far as the Seven Star road in Groveland, are hornblende and quartz hornblende diorite, and at the westward, on either side of the railroad, are other massive outcrops, a southwestern continuation of the "Nubble squid."

The foliated quartz diorite of Long hill, Georgetown, extends across Newbury and Rowley to an outcrop west of Hunslow hill. On the northeast it is cut by the rhyolites from Newbury Old Town, beyond which it is the bed-rock of the mining area in Newbury. Resting upon this rock are glacial erratics — diorite boulders of considerable size. On the south side of Parker street, Groveland, is the Ordway boulder (see Fig. 65), the "Haystack" (see Fig. 66), and a large boulder of quartz augite diorite. At the base of Long hill, Boxford, the outcropping ledge is a massive quartz diorite, including blocks of gneissic hornblende diorite. (See Fig. 68.) Here the magma flowed partially in straight lines and also became variously folded and crumpled, enclosing the blocks and strings of the older diorite. Northeast of Long hill is a high outcrop, known as Lovering's mountain. Here the foliated quartz hornblende diorite is cut by veins of aplite granite. (See Fig. 69.) The hornblende diorite northeast of Bald Pate pond is a segregation of basic minerals in the foliated quartz diorite series and judging from the number of the outcrops further to the northeast, the Rowley and Newbury area must have been the principal mass, which, flowing southwesterly, was erupted into the hornblende epidote gneiss and sedimentary beds of the Georgetown, Groveland, Boxford, and Topsfield area. These quartz diorites, when massive, with slight change in the mineral constituents, become locally, granites — vein-granites or aplites, foliated quartz hornblende diorites, and sometimes granodiorites, as in the area south of Ox Pasture hill in Rowley.

The finest outcrops are to be found at Middleton, Boxford, Georgetown, Byfield, and the Newbury mining region. The microscopic structure of sections of a specimen from Middleton gave: quartz in grains and patches; plagioclase with numerous inclusions of quartz; biotite and epidote; green hornblende with inclusions of biotite and apatite crystals; some titanite and chlorite; ground-mass of secondary quartz and ferrite. Sections from Boxford exhibited numerous quartz grains, well-rounded plagioclase grains, much orthoclase deeply kaolinized, both the plagioclase and the orthoclase having numerous inclusions of quartz and biotite. There were also grains of epidote and fine dust-like ferrite, and muscovite plates arranged parallel to the bedding. The microscopic structure of a section from John Noyes' copper mine in Newbury, closely resembled the sections from Boxford, excepting that there was more biotite, that numerous cubes of iron pyrite were scattered through the dust-like ferrite, and that microliths were of numerous occurrence.

At the corner of School and Liberty streets in Middleton, there is a massive outcrop of typical hornblende diorite, the microscopical structure of which is: brown hornblende, albite, Labradorite, biotite, magnetite, apatite, and a little calcite. The minerals show little sign of decay, in fact, the rock-mass is remarkably tough and fresh. The occurrence of calcite in the section is difficult to explain. North of Wilkins' hill, Middleton, are two outcrops of hornblende diorite, and across the river in Topsfield and Boxford there are frequent outcrops, together with quartz hornblende diorite. At Bald hill, Boxford, this quartz diorite is massive and also foliated, one form running into the other in every sixth of a mile. North of the hill and directly at its base is a fine example of foliation from the massive rock. From this point as far as the Boxford match factory and easterly nearly to Boxford village, the foliated rock is in excess of the massive form. The foliated or gneissic diorite or granite, can always be traced directly to the massive rock. It is therefore plain that all the granitic gneisses are merely foliated forms of the massive rocks, due to the flow of the magma caused by lateral or other pressure previous to its consolidation. A microscopical comparison of the quartz hornblende diorite in the Middleton and Boxford areas, shows foliation and crumpling to be the only differences existing between this rock and the quartz hornblende gneiss. The microscopical structure of numerous thin sections shows them to be composed essentially of the same minerals.

A section from an outcrop north from Middleton near the railroad, had the following structure: quartz, albite, and Labradorite; some orthoclase in simple-twins; brown hornblende biotite, titanite, epidote, calcite, magnetite, and limonite, with apatite crystals in the quartz. Large crystals of titanite are common. Another outcrop gave quartz, augite, diorite, and brown hornblende, paramorphic of augite,

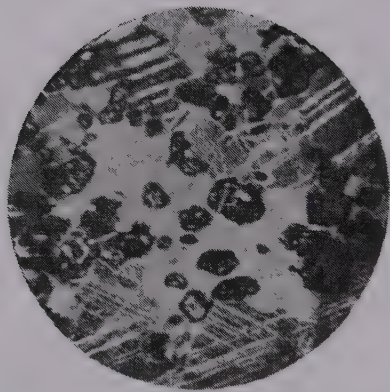


Fig. 71.—PHOTOMICROGRAPH OF WHITE LIMESTONE, SHOWING SERPENTINE PSEUDOMORPHS, DEVIL'S DEN, NEWBURY.

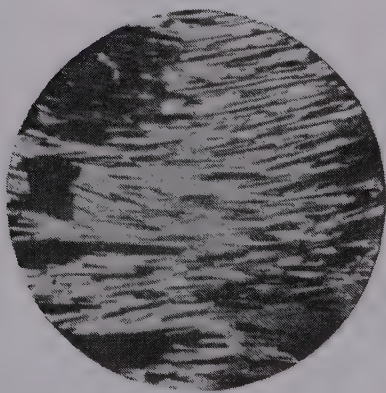


Fig. 72—PHOTOMICROGRAPH OF A BIOTITE CONCRETION IN MICA HORNBLENDE DIORITE AT MIDDLETON.

augite crystals, much biotite, albite, and Labradorite, feldspars finely twinned and quite fresh, some orthoclase mostly altered to saussurite, and kaolin colored by limonite. In the hornblende and augite there was some chlorite and epidote. A quartz vein four inches wide cuts through this outcrop.

In 1904, an electric railway cut the following interesting section across the towns of Middleton and North Andover, following the line of the old turnpike. The first ledge encountered north of Boston brook was a foliated quartz hornblende diorite; the second, a hornblende diorite with little or no quartz and cut by veins of hornblende granite. From this outcrop all others to the North Andover town line were quartz hornblende diorite. The first outcrop in North Andover, opposite the house of Daniel Berry, was a very basic hornblende diorite of the type known as monzonite, having long veins and masses of white quartz. These diorite ledges were easily traced in an easterly direction across Boston brook to the massive outcrops previously mentioned in the Middleton, Topsfield, and Boxford area. On the south and west these formations were traced into North Reading. The quartz diorites also appeared about the base of Will's hill, Middleton, and extended to Forest lake and nearly to the Middleton paper mill. West of the hill, a series of granite veins cut through the diorite rocks. This granite is locally known as "Swan Pond granite," it having its greatest development on the shore of this pond. About Martin's pond the veins and tongues of this granite cut through the diorite in all directions. At Forest lake, it is a vein of coarse micaceous aplite granite, the microscopical structure of which is as follows:

Much orthoclase, some of which is twinned as in the Carlsbad type, shows the basal and second cleavage very perfectly, but the whole section has a strained appearance. In one plate of this feldspar a shadow appears as the plate is revolved on the stage of the microscope, and does not extinguish properly. There are fine plates of microcline. The quartz seen in rods and grains of irregular form resembles graphic granite. Hornblende and biotite are rarely found.

West of the lake this granite outcrops in both large and small masses, having blocks of hornblende diorite and quartz hornblende diorite held as inclusions. Some of the outcrops are a complete breccia of the diorite with the granite on all sides of the brecciated parts. From here the granite and diorite extend a distance of three miles, nearly to the Ingalls' Crossing railroad station, where, towards the northeast, the diorite becomes a mica hornblende diorite containing biotite mica concretions (see Fig. 72), and in a more northerly direction is cut off from the Andover region,

except as included masses in the muscovite biotite granite which surrounds the diorite areas.

On the Ipswich Beach road, near the corner of the Essex road, diorite appears above the surface and other outcrops occur on the north side of Beach street and also in Hamilton, near Miles river. The Beverly end of Folly hill is diorite, which extends on both sides of Bass river towards Hamilton and also towards North Salem. The diorite shows outcrops on the southwesterly shore of Wenham lake, and the Boston and Maine railroad cuts through a ledge which extends to Larch street in Wenham.

The outcropping bed-rock in Salem, west of Salem Neck, is hornblende diorite without quartz, a fine homogeneous basic rock, cut by veins of aplitic granite and narrow dikes of pulaskite syenite with little or no hornblende. Castle hill, Legg's hill (see Fig. 73), Lookout hill, and Ledge Hill park, are elevations of 90 to 160 feet above mean sea-level, and are entirely diorite with a scanty covering of soil. In North Salem there are numerous outcrops of hornblende diorite. Buxton's hill in Peabody is formed of this rock.[1] Mount Pleasant at Proctor's Crossing is a ridge of diorite, which extends in a northwesterly direction for about two miles. The diorite at Danvers Centre is the quartz hornblende diorite from Middleton, in which there are areas showing a gneissic foliated form.

On Chestnut street, Lynnfield Centre, there is an outcrop of hornblende diorite, and an eighth of a mile distant is the Tophet Hill gold mine, a diallage gabbro dike cutting through diorite. At the contact, the rock contains pyrite, micaceous hematite, galena, and fluorite. Near C. W. Hersey's blacksmith shop, a mile from here, there is an outcrop of serpentine peridotite, and outcrops of this rock occur near the railroad one third of a mile to the south. A fourth of a mile east from the railroad station there is a hill of hornblende diorite with a wide dike of diallage gabbro cutting through the diorite. Directly to the north, in the woods beyond Pine hill, are outcrops of hornblende granite, an aplitic form, in a long ridge that is probably a dike. This ledge is locally known as Harris' rock. Southeast of Walden hill and near the town-line between Peabody and Lynnfield there is another outcrop of hornblende diorite. South from Proctor's Crossing, outcrops of hornblende granite extend to the

[1] An interesting dike, a minette form of lamphrophyre closley related to the augite syenite, cuts across the hill at the south and southeast. The composition of this dike rock is orthoclase, feldspar, augite, biotite, and magnetite, while the accessory minerals are zircons, apatite, albite, calcite, and uralite. This is the only minette dike rock thus far recorded in the County.

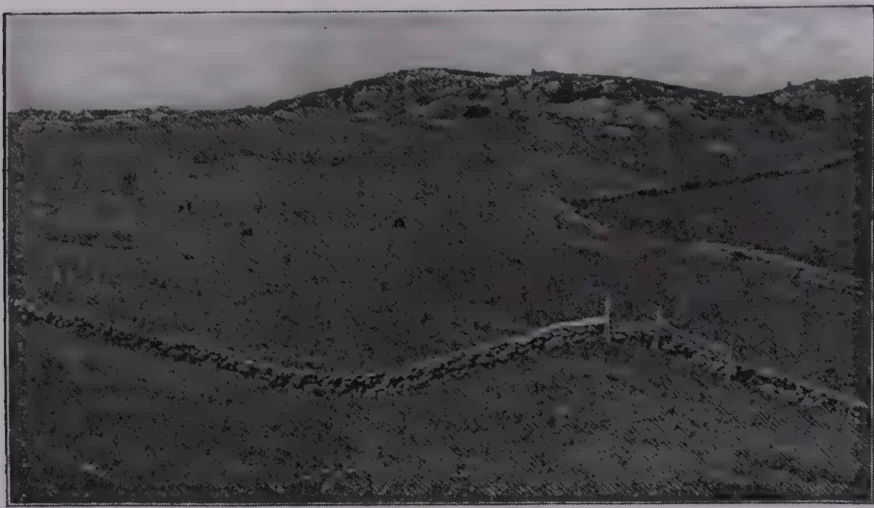


Fig. 73.—LEGG'S HILL, SALEM, A DIORITE LEDGE WITH SUMMIT GLACIATED AND STRIPPED OF DEBRIS.
Kame topography and washed gravels shown in the foreground.

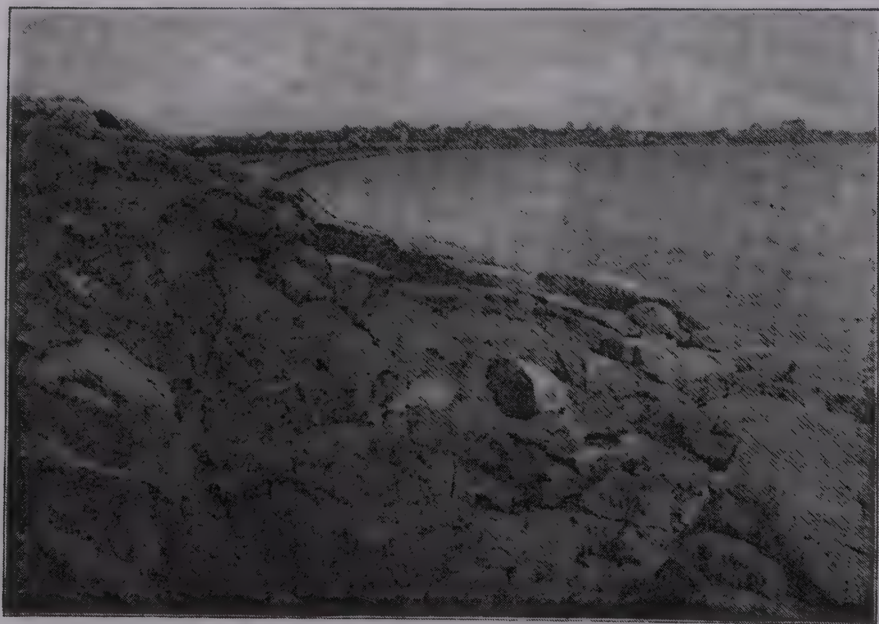


Fig. 74.—QUARTZ HORNBLENDE DIORITE OUTCROP AT CLIFTON, SHOWING BROKEN AND BIZARRE FORM OF HEADLAND.
Marblehead Neck in the distance.

Jacob C. Rogers' estate and easterly to the western part of Buxton's hill. Veins of the Mount Pleasant granite extend northward into Danvers.

In Peabody, about two-thirds of a mile from the Salem boundary, there is a series of outcrops of hornblende granite in contact with the Salem hornblende diorite, where veins and massive tongues of the granite are intrusive in the diorite rock, and many areas of micrographic granite may be seen near the contact of the granite and diorite. There are no intrusive veins or dikes in the granite, for the hornblende granite is the younger rock and cuts the older diorite. No other example has been found in the County where both forms are massive at a contact and where the actual contact is so well illustrated.

On the high land of the Governor Endicott farm at Danversport, there is a massive outcrop of hornblende diorite, which is also the bed-rock under the clay-beds at the west side of the hill. The diorite also outcrops on the north side of Lindall hill, and from Summer street across Putnamville to West Wenham there are numerous other outcrops.

Gradual transitions from massive hornblende diorite to amphibolite gneiss may be seen on a large scale in a railroad cut north of the Putnamville station, and also at Danvers Centre near the corner of Newbury and Dayton streets. In these diorite masses the minerals are elongated and secondary feldspars and calcite are developed in lines and around small masses of hornblende and magnetite. The latter is largely changed to hematite and limonite which gives the rock-mass a decidedly gneissic appearance, but it does not in the least resemble the hornblende epidote gneiss which only occurs in regions of granitic rocks. Another area of this foliated diorite may be seen by the roadside at Putnamville near the Wenham line. The diorite of the entire Putnamville area is cut by veins or narrow dikes of aplitic granite, and wherever the diorite rock occurs in massive form, some part of the area will be seen to be gneissic, due to the flow of the diorite magma previous to its consolidation.

West of Hawkes' brook in Peabody, the railroad cuts through a hill of quartz hornblende diorite which extends into Saugus with one outcrop on the east side of Hawkes' pond, half a mile south of the railroad track. This diorite also appears on both sides of Howlett's brook, and from the north and westerly sides of Breakheart hill in Saugus, it continues into Middlesex County. Between Little Castle hill and Breakheart hill the quartz diorite outcrops, and southeasterly one half a mile across Main street are six outcrops extending into Melrose. Frequent outcrops of quartz diorite appear at the northwesterly end of Walden pond, on the

entire easterly side of Pranker's pond, and at the western end of Glen Lewis pond. On the southern side of Glen Lewis pond, stand Mount Gilead and Burrill hill, both outcrops of a very granitic quartz granodiorite rock. Some of the rock-sections from Mount Gilead are very near a true hornblende granite, orthoclase being in excess. Other sections show triclinic feldspars in excess of orthoclase.

Baker's island, in Salem harbor, is a massive outcrop of quartz diorite, a tonolite or vein-rock mass of two forms. The ledges on the west and northwestern part of the island are a fine-grained highly mineralized rock having numerous small quartz veins, while the outcropping rock on the central and eastern portions of the island is a coarser form with much hornblende and biotite. A wide vein of milky quartz may also be seen on the northeastern part of the island. This coarse quartz diorite is cut by a wide porphyritic diabase dike running across the island from east to west, and a number of smaller dikes cut the island from north to south. One large hornblende olivin basalt dike, cutting through the island from the southwest to the northeast, is the same rock as the Pope's head formation, and also a part of Eagle island of which the principal mass is quartz diorite. In a southwesterly course this rock forms outcrops at Peach's point, on the shore of Marblehead, at Orne's island, Gerry's island, the headland on which Fort Sewall is built, and also on the headland beyond Devereux beach. Small dikes and veins of this quartz tonolite diorite cut the hornblende diorite and the hornblende granite at Devereux and Clifton, and may be observed in several cuts along the line of the railroad.

Little Misery island, having an area of three acres, is an outcrop of hornblende gabbro, with a small outcrop of quartzite near the channel which separates the island from the Great Misery. Probably other sedimentary rock in the bottom of the channel would account for the line of weakness which permitted the sea to form this passage. On the southern and eastern side of Great Misery, cliffs rise very abruptly to a height of thirty feet, and are deeply cut by dikes which the sea has removed, leaving steep-sided cuts extending into the shore of the island.

The bed-rock of Marblehead is largely hornblende diorite with massive dikes of basalt and diabase. (See Fig. 74.) Numerous outcrops occur in the central part of the town and on the seashore near Bass rocks. The whole diorite area is in part brecciated by syenite and aplite veins, which may be observed in road-cuttings and other deep cuts in all parts of the

Fig. 75.—HORNBLENDE GRANITE QUARRY AT ROCKPORT.
Showing jointing of the formation.

Fig. 76.—HORNBLENDE GRANITE QUARRY AT LANESVILLE, GLOUCESTER.
Showing gradual increase in thickness of the joint planes.

town. On the shore at Clifton the quartz diorite rocks are cut by dikes of aplitic granite.

The following cuttings, which may be taken as typical of the whole series, have microscopical structures as follows :

No. 1. Jersey street, augite diorite : Augite, hornblende, orthoclase, plagioclase, biotite, magnetite, quartz, apatite, micro-zircons, and some garnets. The quartz is apparently original as it has inclusions of zircons and apatite.

No. 2. Abbot street, augite diorite : This has more orthoclase and large masses of apatite crystals in both the orthoclase and plagioclase ; otherwise as in No. 1.

No. 3. Abbott street, augite diallage diorite gabbro : Large masses of augite, some diallage, green hornblendé, biotite and drusy quartz, masses of large micro-apatite crystals, some zircons, a little apatite, plagioclase somewhat kaolinized, and a little orthoclase. The biotite is of the red color so noticeable in the elæolite zircon syenite. Some of the augite is seen as inclusions in the hornblende.

No. 4. Jersey street, augite olivin hypersthene diorite gabbro : This rock is perfectly fresh, no decomposition being noticeable in any of the minerals. The probable genesis of the crystallization of these minerals from the magma was magnetite, zircon, apatite, augite, olivin, hypersthene, biotite, hornblende, plagioclase, orthoclase, and quartz.

East of the Andover Theological Seminary there is an outcrop of the hornblende diorite known as Rabbit rock. Other outcrops extend northerly from this point to Clay Pits hill, a distance of about one mile. East of this line of outcrops may be found the mica granite of North Andover. The diorite outcrops in the Andover region have numerous veins and large dikes of fine mica granite cutting through them, and in the foliated parts of the granite there are masses and blocks of diorite and slate held as inclusions, indicating that the older bed-rock of this area was the basic hornblende diorite which has since been cut by the micaceous granite. Near the Andover almshouse there is an outcrop of hornblende diorite, which is fifteen hundred yards in length and about three hundred yards in width, and east of this area across the Andover turnpike is a small outcrop of the muscovite biotite granite. West of Stevens' woolen mills, and in a northeasterly direction from Indian ridge, occurs a massive outcrop of typical hornblende diorite which extends nearly to the bank of the Shawsheen river. Six outcrops of hornblende diorite appear on the eastern side of Carmel hill. Contacts of these rock formations are not exposed.

CHAPTER V

HORNBLENDE GRANITE

THIS name is given to the granite rocks of Cape Ann and the eastern part of the County. Under the general type there are several varieties, either coarse or fine grained, and containing little or much biotite. The Peabody and Lynnfield granites contain little biotite, while in the Gloucester and Rockport granites (see Fig. 75) there is much biotite. There are also local variations in color due to inclusion of other minerals in the feldspars. The Pigeon hill and Lanesville granites (see Fig. 76) are of a greenish color, while the granite from Wenham and Ipswich is grayish white. In a few areas the quartz is in excess, while in others there is little quartz and that is of a smoky color. Examples of this are seen in the upper opening of the Rockport Granite Company's quarry at Rockport.

From an economic point of view the hornblende granite is the most valuable rock formation in the County. The perfect rift and cut-off permit the rock to be easily worked into a commercial stone of pronounced durability for building and bridge work. Its susceptibility of receiving a good polish makes it desirable for interior construction and also for cemetery work.

Thin sections of this hornblende granite when studied with the microscope, show it to be composed of the following minerals: orthoclase, microcline, microperthite, which is composed of simple-twinned albite crystals intergrown across the twinning plane of the microcline; hornblende of the green variety, sometimes altered to glaucophane; much quartz and biotite; with fluorite, garnets, zircons, actinolite, and magnetite as accessory minerals in the feldspars. Nearly all of the rocks of this formation show evidence of subjection to a great strain or crushing force, as most of the original minerals have numerous cracks which have been filled with a secondary formation, either biotite or glaucophane.

Minerals in the thin sections from the Cape Ann Granite Company's quarries at Rockport, are as follows: quartz in large patches, which is greatly cracked and crushed, orthoclase, microcline, some plagioclase, microperthite, hornblende, a little biotite, some muscovite, large patches of magnetite, some microscopic zircons of considerable size and epidote and limonite. The feldspars are much decomposed. This section is nearly identical with sections of the same rock from Wenham, Hamilton, and Ipswich.

Fig. 77.—RACCOON ROCKS, MANCHESTER.
An outcropping ridge of hornblende granite.

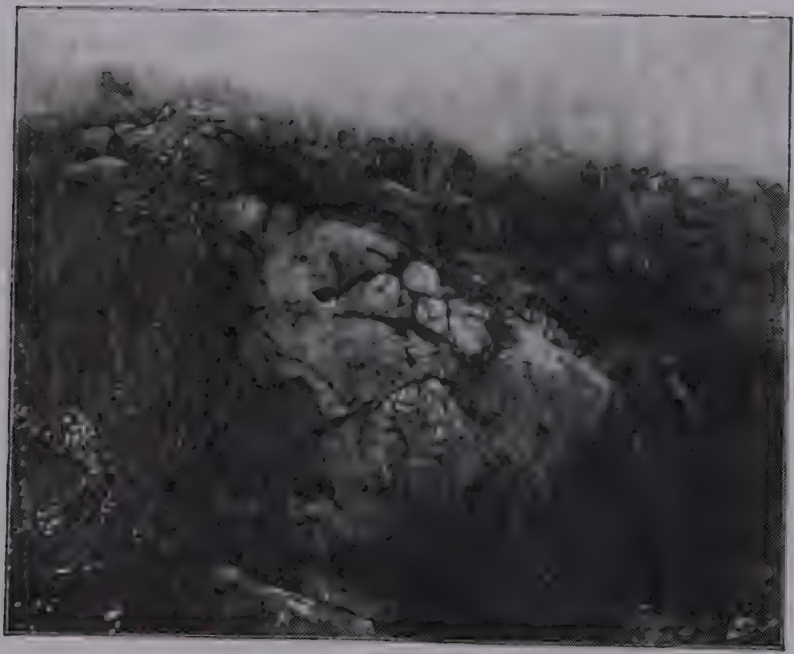


Fig. 78.—HORNBLENDE GRANITE OUTCROP IN THE RACCOON ROCKS, MANCHESTER.

The microscopical structure of other sections of this rock taken from the Cape Ann Granite Company's quarry at Bay View, is as follows: quartz in large patches; orthoclase, much of which is in simple twins after the Carlsbad type; multiple-twinned plagioclase; probably anorthite; some basal sections of microcline; green hornblende; some biotite and muscovite; much magnetite, with numerous micro-zircons of considerable size held as inclusions in the biotite and orthoclase. Part of the multiple-twinned plagioclase is clearly albite. In some sections there are fine examples of microperthite — intergrowths of albite and orthoclase. All of the quartz masses show incipient cracks, and in some cases they are broken. Near these quartz areas the feldspars are somewhat decomposed.

There are several distinct areas of this formation. The Saugus area is nearly continuous east and west from the Pig rocks, off the Swampscott shore, to North Saugus. From Mountain street in Lynn, to near Vinegar hill, it is cut by rhyolites, and at North Saugus it is cut by quartz augite syenite extending from the Lynnfield area. The Lynnfield and Peabody granite reaches westerly to Proctor's Crossing, northerly to Danvers, and southeasterly to Marblehead neck and Tinker's island, where it is separated from the main mass on Marblehead and Marblehead neck by rhyolites. Another area is central in Danvers and East Wenham, and extends westerly to the Danvers and Topsfield town lines, northerly to the village of Topsfield, and easterly across Wenham and Hamilton to Ipswich. This area is cut by quartz augite syenites in East Wenham, and Hamilton and between Hamilton, Ipswich, and Essex. Another area is between Bass river, Beverly, and Rockport, and presents an almost continuous series of outcrops cut occasionally by the quartz augite syenites, nordmarkite, and pulaskite syenites. The whole of this area is cut by numerous narrow basic dikes.

The hornblende diorites which extend across Marblehead, Salem, Peabody, and Danvers, are cut by the granites at every contact that has been found, and as masses of diorite exist between most granite formations, they must be considered as distinct masses of granite. The microscopical structure of these various granite masses shows variation but not enough to create distinct forms. The trend of the whole series is approximately northeast to southwest, but the trend of the outcrops of the individual mass is usually east and west, or north and south.

East of Wenham lake, the hornblende granite outcrops on Dodge street, North Beverly, on both sides of Norwood's pond, and on the north side of Brimble hill. South from this hill and extending to Montserrat and to the city of Beverly, is a series of hornblende granite outcrops, one of which is the elevation on which the Salem reservoir is built. It also

appears at the corner of Bomer and Maple streets, West Wenham, and extends into the northern part of Danvers, and is also found in the valley between Pingree's and Towne's hills in Topsfield. On both sides of Nichols' brook in Topsfield, there are five outcrops of the red granite, boulders of which are so often seen in the boulder-till of Danvers and Beverly. One outcrop is quite massive and stands at an elevation of one hundred and twenty feet. In Middleton, on the south side of this brook, appear outcrops of hornblende granite, and across the Ipswich river is Oak hill, a massive outcrop having an elevation of one hundred and forty feet. In West Boxford, north of the village, are outcrops which connect with the large exposure at Lakeside farm beside Johnson's pond. This granite is probably a vein or tongue from the North Andover area intruded into the old Cambrian sedimentary beds. At Groveland, near the railroad, there are several outcrops of this hornblende granite of a foliated or gneissic formation.

Hornblende granite is found at Ipswich, about Heartbreak hill, and on a small island in the tidal marsh. It also forms the ledge on which the spindle buoy is set at the entrance to Plum island sound from Ipswich bay, and the spindle buoy at the entrance of Essex river is fastened to a similar ledge. On either side of the highway from Ipswich to Woodbury's crossing in Essex, all the outcrops are hornblende granite, and extend easterly to Hog island and northeasterly on both sides of Castle river. West of Black brook in Hamilton and Topsfield, all the ledges are of this granite, the outcrops also extending southeast of Vineyard hill to Asbury Grove and to the village of Wenham, where one ledge occurs in the rear of the town hall. Moses' mountain in Essex, is a massive outcrop of the hornblende granite, rising to a height of one hundred and eighty feet above mean sea-level. From this elevation a ridge of granite extends northerly, a distance of over three miles to Millstone hill, east of which there is a series of steep ledges known as the Raccoon rocks. (See Figs. 77, 78.) At Coffin's beach, West Gloucester, the hornblende granite outcrops south and east of the "Two Penny Loaf," and at several places in the tidal-marsh and in sand-dunes south of the beach. (See Fig. 79.)

Micrographic Granite or Granophyre. — In a contact surrounding the granite areas, and forming a zone between the granite and the augite syenite and the diorite areas, is a micrographic granite which invariably cuts the diorite and augite syenite by long tongue-like and dome-shaped masses. It becomes an aplite dike granite at contacts with diorite. At contacts between the augite syenite and granite it is merely a fine-grained or micrographic granite. It should be considered as a contact-zone and

Fig. 79. — HORNBLENDE GRANITE OUTCROPS BETWEEN WHICH A BASIC DIKE ROCK HAS BEEN REMOVED BY DISINTEGRATION.
South from Coffin's beach, West Gloucester.

Fig. 80. — HORNBLENDE GRANITE BOULDER, AT ESSEX.
32 feet high, 25 feet wide, 40 feet long; estimated weight, 3,763 tons.

not as a distinct rock formation. When studied from thin sections under the microscope in polarized light, it is seen to be different in structure from any variety previously described. The minerals are largely microcline, microperthite, orthoclase and albite. These are, by the addition of quartz grains, again broken up into micropegmatite, forming a beautiful mosaic. Other minerals are augite, titanite, hornblende, biotite, hexagonal sections of apatite, numerous zircons, some colorless garnets, and magnetite. In some of the sections there are fine masses of glaucophane, a probable decomposition product of hornblende. One section has microcliths of ægirine in the orthoclase and larger quartz grains. The specific gravity of the feldspars in the crushed rocks, when passed through the 90 mesh sieve and separated in the Thoulet solution, as determined by the Westphal balance, gives 2.65 for the quartz and some albite, 2.57 for the microcline and orthoclase, and heavier minerals range between 3.2 for augite, and 4.4 for zircon.

Occupying the region between Fresh Water Cove village and the West Gloucester railroad station, and extending in a southwesterly direction across Magnolia, Manchester, and to the Beverly shore, is an outcrop of granophyre. Towards the north this formation cuts the hornblende granite and augite syenite from Eastern point to the shore-line at Bass Rocks. From Rocky Neck, East Gloucester, to Bass Rocks, the contact of this granophyre and the hornblende granite is strongly marked and easily followed. Across Little Good Harbor beach and opposite Salt island, to the inner point of Briar Neck, there are numerous tongues of this rock intruding into the hornblende granite, while the main mass of the rock is seen on the outer side of Salt island. It reaches the mainland on the shore in the middle of Long beach where it divides, one part following the shore-line to Cape Hedge and Emerson's point, and reaching across to the west side of Loblolly cove, while the other mass cuts across the granite to Gap head and Straitsmouth island, and appears in numerous outcrops from Whale cove to the town of Rockport. Between Freshwater Cove village and West Gloucester, this granophyre has the appearance of a massive flow; and it has a similar character where it crosses Eastern point from Rocky Neck to Bass Rocks. On Emerson's point and Gap head, however, it is seen in dome-shaped masses a few feet in diameter, clearly embedded in granite and also varying from this to extensive eruptive forms. It is probable that this entire formation has a massive, intrusive, granitic structure, which has in places widened out into dome shapes, while in others it has become contracted into dike forms from a

few inches to a number of feet in width. It is clear that some of the rounded masses are seen as surface outcrops, by the erosion of the surrounding granite at a comparatively recent date.

The microscopic structure of this rock, as shown by a selection from the numerous thin sections from different outcrops, is as follows:

No. 1. From Eastern point, midway between Bass Rock and Brace's cove: Orthoclase, quartz, chlorite, uralite, magnetite, and numerous small grains of titanite. With a high power objective under crossed nicols, the feldspars and quartz present the appearance of a mosaic. The feldspars are microperthite intergrowths of albite and orthoclase.

No. 2. From the outer side of Salt island: Micropegmatitic quartz and feldspar grains, the feldspar grains being tabular Carlsbad twins (always microperthite), augite, green hornblende, some biotite, magnetite, iron pyrite, and large sections of colorless garnets in the micropegmatitic quartz and feldspar areas. With high power objectives, even the smallest feldspar grains are seen to be microperthite. There are, also, some micro-zircons as inclusions in the feldspars. The entire section shows that the rock has been subjected to great strain, for much of the hornblende and some of the feldspars are crushed and broken. Decomposition in the hornblende has produced feathery-formed glaucophane.

No. 3. Near Brace's cove, southeast: Quartz feldspars, hornblende, chlorite, glaucophane, and limonite. The quartz and feldspars are arranged as in the other slides. The orthoclase, which is microperthite, micropegmatitically arranged, has inclusions of hornblende, limonite, and quartz grains. The evidence of great strain and crushing force, sufficient to separate the quartz grains from the feldspars, is easily detected. In many cases a rim of chlorite surrounds each grain, while in some instances the limonite surrounds the quartz and feldspar grains, giving the section the appearance of a clastic rock, usual in all of the granulites.

Many micro-sections of this rock from various outcrops have been studied, and the results all point to the conclusion that this extensive formation in the Cape Ann hornblende granite area has a granitic structure, and has crystallized from the magma in an aggregate of small grains, partially metamorphosed by plastic deformation subsequent to solidification.

Thompson's mountain in Cape Ann park, is an outcrop of hornblende granite swept bare of debris, which rises to an elevation of two hundred and twenty feet above sea-level. Essex avenue, about one mile distant, is laid out in a dip in this granite which rises by the side of the road to a height of nearly one hundred feet. From Brace's cove to Light House point, East Gloucester, all of the massive outcrops are hornblende granite. Aporhyolite appears in a series of dikes on Eastern point, and also forms Halfway rock, the Dry breakers, and Gooseberry islands. These intrud-

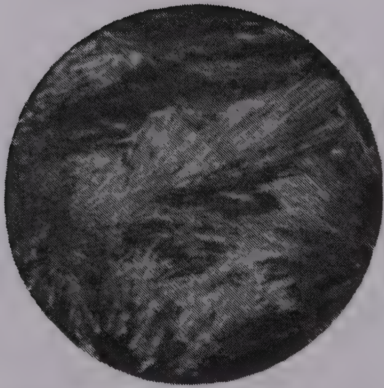


Fig. 81. — PHOTOMICROGRAPH OF ACTINOLITE IN A MASS OF FAYALITE.
Rockport.

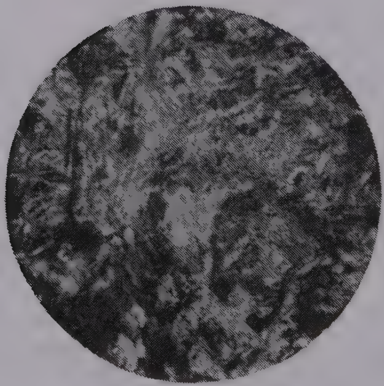


Fig. 82. — PHOTOMICROGRAPH OF BIOTITE OLIVIN PERIDOTITE.
Skug River, Andover.

ing aporhyolite dikes cut the granite and indicate its greater age. North of the Oak Grove cemetery in Gloucester, in the Pomeroy quarry, the hornblende granite appears in the form of a pink feldspar, rich in well-crystallized minerals which occur in geode-like pockets in the massive granite. Along both sides of Mill river, the outcrops of hornblende granite are very massive and extend to the augite syenite rocks, north of Annisquam village. South of the canal, at Stage Point head, Gloucester, the outcropping bed-rock is hornblende granite, and extends parallel with the shore to Fresh Water cove and Magnolia. From Emerson's point, Rockport, to Milk island and Briar Neck, all of the outcrops of bed-rock are hornblende granite. On the shore opposite Milk island there is a bed of arkose, a conglomerate granite, reconsolidated from an older granite mass.

Around Poole's hill, the outcrops are hornblende granite and along the shore from Sandy bay to Lanesville, this granite forms a fringe between high- and low-water mark.

In 1880, Fayalite was found by the author in this hornblende granite at Rockport. This rare mineral was first collected at Fayal, in the Azores, by Baron Humboldt. It has been found in the granite of Mourne mountain, Ireland, and microscopic crystals have been discovered in lithophase occurring in rhyolite rocks at the Yellowstone Park. The specimens collected at Rockport were parts of a long crystalline mass found at a depth of sixty feet below the surface and near the base of a large boss or vein of pegmatite. Here the Fayalite occurred as a lenticular shell of varying thickness from twelve to sixteen inches in diameter and of a dark resinous-green color. In connection with this mineral were found masses of an actinolitic mineral of the usual leek-green color. (See Fig. 81.) A chemical analysis of this Fayalite made at the Sheffield Scientific School, New Haven, gave the following results:[1]

SiO^2	30.08
FeO	68.12
MnO	.72
H_2O	.80
	99.72

Specific gravity 4.318.

Off the shore of Manchester is Kettle island, an outcrop of pink feldspar granite cut by a series of very basic basalt dikes. Great Egg rock

[1] American Journal of Science, Vol. XVI.

is a bare ledge of hornblende granite, on the surface of which are several patches or remnants of a sill dike of basalt, the upper parts eroded and cut away by the action of the sea. Graves' island, which recently has been formed near the Manchester shore, is a massive outcrop of hornblende granite. Within eighty years a cart-road led to this island which, in 1901, was nearly an eighth of a mile from the shore with a deep-water channel between.

The microscopical structure of an aplite vein or dike granite cutting the hornblende diorite at Castle hill, Salem, is shown in the following sections:

No. 1. Quartz and orthoclase in micrographic structures, some lath-shaped plagioclase, probably anorthite, with epidote, limonite, and polysynthic-twinning in calcite, titanite and its decomposition product leucoxine, and cubical iron pyrite.

Nos. 2–3. Same as No. 1, with some green hornblende and biotite.

No. 4. This section is from a contact with the diorite. Much titanite and pyrite. Orthoclase, plagioclase, and quartz, with numerous plates of calcite and crystals of apatite.

No. 5. Aplite in contact with a diabase dike. Orthoclase, plagioclase, Labradorite, green hornblende, augite, epidote, calcite, and magnetite, numerous apatites, finely-twinned glassy feldspars seen with numerous polysynthetic-twinned plates of calcite, some secondary quartz, biotite, and magnetite developed at the contact with the dike-rock.

An aplite vein cutting quartz hornblende diorite on the shore below Clifton heights at Marblehead (see Fig. 84), is fine-grained and usually of a light red to gray color, and shows nothing but quartz and feldspar. Under the microscope, in thin section, micrographic intergrowths of feldspar and quartz are seen, with a little green hornblende, brown biotite and some titanite and magnetite.

The ledges in the area between Cherry hill, North Beverly, and Folly hill, in Danvers and including the same, are hornblende granite. Extending from Beverly Farms to Prides Crossing there is a ridge of this granite about one mile in width with continuous outcrops. Snake hill at Montserrat, is also hornblende granite. Other outcrops occur in Beverly on Railroad avenue, Broadway, Prospect hill, and Goat hill at the mouth of Bass river. On Marblehead Neck, the granite from Tinker's island is found by the shore where it cuts the slates, sandstones, and quartzites. It also extends across the harbor and makes its appearance about an eighth of a mile northeast of the causeway, and also cuts the diorites near the railroad station.

Fig. 83.—MUSCOVITE BIOTITE GRANITE, FOLIATED.
Jones Quarry, South Lawrence.

Fig. 84.—APLITIC GRANITE DIKE CUTTING QUARTZ HORNBLENDE DIORITE, AT CLIFTON, MARBLEHEAD. THE ARROWS INDICATE THE DIKE.

In Peabody, the west end of Buxton's hill is hornblende granite, and towards Proctor's Crossing are three outcrops. This granite also appears on Mount Pleasant on the Jacob C. Rogers estate and again near Felton's corner. A short distance away, in Danvers, there is an outcrop north of the Peabody and Danvers boundstone. This long tongue of granite is intruded into the diorite area from the mass south of Proctor's brook in Peabody. South of this brook, across the town of Peabody to Indian hill, Wyoma, in Lynn, all the outcrops are of this granite and cover an area nearly four miles east and west, and three miles north and south.

The microscopic structure of thin sections taken from Davis Brothers' quarry near "Ship rock" in Peabody, is as follows: much quartz in large xenomorphic areas, some orthoclase, much plagioclase well twinned, probably Labradorite, much magnetite and limonite. A number of the thin sections show that the rock has been subjected to great mechanical strain, for all of the multiple-twinned feldspars and the quartz areas are cracked, broken, and faulted, a serious defect in the rock, permitting the minerals to separate and the whole rock-mass to crumble. This is so pronounced that it is nearly impossible to make a good thin section for microscopical study. There is much chlorite developed from the decomposition of the hornblende, which gives the rock its green color.

Mountain street, Lynn, is laid out over a large outcrop of hornblende granite, and all the outcrops extending from this point to Dread ledge, Swampscott, and to Phillips beach, are of the same granite.

The microscopical structure is as follows: quartz in large irregular crystalline forms, with well twinned albite in excess of orthoclase. Some of the orthoclase crystals are microperthitic intergrowths of albite, one section of microcline showing the basal cleavage. Numerous aggregates of brown hornblende and biotite, some augite surrounded by hornblende and magnetite, a few zircons, chlorite, and uralite. Some of the microperthite areas are micrographic. Cubical iron pyrite crystals appear in the hornblende and biotite areas. Quartz is in excess of all the other minerals and shows incipient cracks and in some areas is crushed and broken, the cracks being filled with secondary silica or chalcedony. Zonal structure is well developed in some of the orthoclase, and in one of the feldspars there is a red garnet crystal. Allanite and epidote are also seen in some sections.

Dolphin rock, the Great and Little Pig rocks, Ram island, and Tinker's island, are outcrops of the same formation. A narrow ridge outcrops at Clifton and at Devereux, with diorite and granophyric granite on both sides. From Tinker's island the granite extends to the shore of Marblehead Neck where it cuts slate, sandstone, and quartzite, and in turn is cut by veins of quartz, porphyry, and porphyritic diabase. In Lynnfield,

South Lynnfield, and Peabody, all of the outcrops south of the Lowell branch railroad tracks are hornblende granite. North of Main street, in Saugus, the outcrops are granite. Near the school-house on this street, the outcropping ledge in the form of a ridge is granite, which extends to the Saugus poor-farm. On Denver street, Saugus Centre, the granite has a contact with aporhyolite which outcrops on both sides of the granite mass. In a quarry near the railroad track on Denver street, specimens may be obtained, showing numerous forms from aporhyolite trap and red granite to a simple fused granite. South and southwest of this contact there are three outcrops of a red aporhyolite on Essex street, and four outcrops at Cliftondale, extending by other outcrops to the tidal marsh at East Saugus and northerly across Saugus Centre to Vinegar hill.

Porphyritic Granite. — This formation occurs in Newburyport, West Newbury, and Amesbury. It is much like the hornblende granite, but contains numerous large porphyritic crystals of microcline. The whole area has been subjected to great strain by a down-throw fault in the Parker river valley between Georgetown and West Newbury. This strain is seen in the large porphyritic crystals, nearly all of which are cracked, bent, or broken.

Extending along the bank of the Merrimac, from the Artichoke river to "The Laurels," are outcrops of coarse porphyritic granite. Six outcrops also appear at the south and southwest in West Newbury extending nearly to the base of Indian hill, and veins and tongues of granite extend to the Byfield railroad station. Less than one half of a mile from the outcrops near Indian hill, the ordinary hornblende granite appears. A fine-grained aplitic dike granite also extends from a point east of Central street in Byfield, nearly to the Chipman silver mine. It is therefore evident that the principal mass of this granite lies at the northward, the magma flowing southward and cutting the slates and sandstones of West Newbury and the diorites of Newburyport and Newbury.

This porphyritic granite is also found north of Monday hill, in Amesbury, and southeast of Grape hill, between Amesbury and Salisbury. There are numerous outcrops east of Powow hill, north of Clark's pond, and extending to the brook on the east side of Black river, some of which are foliated in form. On the Davis farm, near the Chain bridge, an outcrop appears that is slightly porphyritic. The feldspar phenocrysts in the outcrops at "The Laurels" are sometimes six inches long, but usually cracked and broken, with hornblende mica and quartz filling the cracks. The feldspar phenocrysts are microcline.

Specimens of porphyritic granite from "The Laurels," from Amesbury, and from beside High street, near the Artichoke river, show the following microscopic structure:

Much quartz, orthoclase, and albite, parts of which are perfectly fresh, but all more or less crushed and broken. The cracks in the feldspars are filled with secondary quartz, calcite, and muscovite, and there are also some large areas of crystalline calcite. Much chlorite, some magnetite, large patches of limonite, a few small areas of hornblende appear, also numerous zircons. The quartz is allotriomorphic — the quartz of typical granite. The extinction angle on the base of one of these crystals was 12° on the second cleavage.

Numerous apatite crystals are seen in the chlorite and large phenocrysts of microcline microperthite, some of which are five inches long, and one and one half inches broad, are scattered through the rock-mass. They are usually bent, broken, and partially crushed.

In Amesbury, part of the area of this granite is gneissic. The foliation is north and south; the dip east. In this gneiss the large phenocrysts are filled with inclusions of quartz and albite. East of Powow hill, the outcrops show the following microscopical structure:

Orthoclase, albite, quartz, and hornblende, with muscovite and biotite. The large phenocrysts of feldspar are as in the other sections, but show more distortion and crushing. The cracks are filled with muscovite and quartz and the general mass of the quartz seems to be hypidiomorphic. Numerous fluid inclusions are seen in the quartz. The hornblende is very weak, being largely decomposed to limonite and calcite. There is much titanite and its decomposition product leucoxene, also considerable chlorite. Zircons with extinction parallel to the prism and pyramid are abundant. Some secondary glassy albite feldspars are scattered through the section; the original feldspars being crushed and faulted, and the cracks filled with quartz, muscovite, and calcite. The quartz and muscovite are plainly secondary minerals due to metamorphism of the feldspars. In some of the areas which show this crushing, all of the albite crystals are filled with glassy microliths.

CHAPTER VI

MUSCOVITE BIOTITE GRANITE

In the northern part of the County, and occupying nearly the whole region of Andover, West Andover, South Lawrence, a large part of North Andover, Bradford, Ayer's Village in Haverhill, and extending into New Hampshire, the bed-rock is muscovite biotite granite passing into a foliated form. In Andover and North Andover, the strike is east 40° north, parallel to the metamorphic slate.

On the east side of the Shawsheen river, the bed-rock outcrops which skirt the base of Carmel hill are a coarse muscovite mica-granite. There are other outcrops of this granitic gneiss at Pine hill and on Highland and Summer streets. From the Andover Theological Seminary to Foster's pond, and also on both sides of Skug river, there are occasional outcrops scattered over the area. In several old quarries, both a fine- and coarse-grained mica-granite is found. On Lowell street, south of Hackett's pond, there are five outcrops, and east of Skug river there is a massive outcrop of nearly bare rock having an elevation of 280 feet. These outcrops extend to Swan pond in North Reading, to Forest pond in Middleton, and as far west as Boston brook. West from Ingalls' Crossing station there are five outcrops beside the Middleton and Andover turnpike.

West of the Andover poor-farm there is a large outcrop of this coarse granite, and Den rock, in North Andover, is of the same formation. An outcrop at Machine Shop village, in North Andover, is cut by a vein or dike of aplitic granite. Across Cochichewick brook, at the western base of Osgood's hill, are three outcrops, and an exposure occurs by the roadside near Tyler's hill in Andover.

Muscovite Biotite Granite, Foliated. — This white gneiss occurs in a broad, irregular belt, having its greatest development in Andover where it occupies the greater part of the area of the town and extends southward into Middlesex County. At Ballardvale, it occurs in massive formation. The best exposures are at the W. J. Jones quarries in South Lawrence, where it is worked for foundation stones (see Figs. 83, 85, 86). Here the coarse gabbro and basalt dikes and sills are intruded into the mica-granite

Fig. 85. — GRANITIC WHITE GNEISS ARKOSE.
Jones Quarry West Andover.

Fig. 86. — GRANITIC WHITE GNEISS, WITH MUCH MUSCOVITE.
Jones Quarry, South Lawrence.

and probably have metamorphosed the rock-mass. Garnets are abundant. They are always of secondary origin in igneous rocks and are due to metamorphism.

This white gneiss, with its pegmatite masses and veins cutting the bedded mica-schists and sandstones, is without doubt an igneous eruptive rock-mass. Crushing may be seen in this quarry, producing a granite arkose. The strike at this point is east 20° north; dip 85° south of west. The microscopic structure of sections of this rock is: coarse masses of orthoclase, microcline, quartz, muscovite, and garnets, cemented together by a thin film of secondary quartz. Numerous inclusions of quartz, biotite, and muscovite, occur in the feldspars. Long tongues of this gneiss extend north and northeast, cutting the bedded mica-schists at Salem, N. H., and in the northwestern part of Haverhill. At Ayer's Village, the rock is a coarse- to fine-grained biotite gneiss, the color varying from white or light-gray to dark-gray. At North Andover it is quite massive without distinct foliation, while at West Andover and South Lawrence it is well foliated and of a uniform color. The narrow belt that runs into the bedded mica-schists, slates, and sandstones of Lawrence, Metheun, and Haverhill, shows lines of contact in various places. Some of these contacts cut across the strike of bedded mica-schists and sandstones, and it is seldom that an outcrop does not contain veins of granitic gneiss cutting through the schist. North of Ayer's Village this gneiss cuts the schists parallel to their bedding-planes and sheets of schist torn from the principal mass are seen projecting into the granitic gneiss. Here is the most striking proof of the eruptive character of the granitic gneiss. These inclusions of schist, in the granitic white gneiss, vary in size from a few inches to many feet in length, and may be linear or very irregular in form. A large inclusion of a biotite-schist occurs on Main street, Andover, south of Carmel hill, and contains hornblende, which is almost wholly wanting in the granitic white gneiss. Rounded and irregular bosses of hornblende diorite also occur in the gneiss.

The presence of numerous pegmatite dikes in this granitic gneiss also indicate its eruptive origin. These dikes, or masses, cross and also run parallel to the foliation of the granitic gneiss. The contact is never sharp, and they frequently merge into the gneiss, both containing the same minerals. Garnets are abundant in the gneiss and pegmatite in the Andover area.

The ordinary form of the granitic gneiss is a light-colored and rather fine-grained rock. The amount of biotite varies considerably. Wherever

it is most abundant, the rock is a light-gray, well foliated gneiss; where least abundant it is nearly white and of a granitic appearance. In some localities in North Andover it becomes perfectly massive. An excellent example may be found near the Marble Ridge railroad station. The strike of the main body of this gneiss is north 20° east, and the dip 45° west. Joint-planes cut the gneiss in two or more directions, one nearly or quite parallel to the foliation and others at a right angle.

Microscopically examined in thin section, this rock is found to be composed of a granitic mixture of feldspars, quartz, and plates of muscovite, with some biotite. Hornblende is rare. One section shows green hornblende which seldom is seen macroscopically in new exposures in the field. The feldspars usually present an allotriomorphic aggregate of grains. Orthoclase is most abundant, and an acid plagioclase is of common occurrence. Microcline also occurs in large, irregular grains. Micrographic intergrowths of orthoclase, plagioclase, and quartz are seen, the latter taking the form of narrow irregular curving or angular inclusions converging towards the center of the feldspar grains. Titanite is present in small, rounded, and lenticular grains. Red garnet is the most common accessory mineral.

In an area about a mile wide, on the west side of Crystal lake (Creek pond) in Haverhill, the granite gneiss shows granulitic facies towards the contact with the mica-schist. South of the lake occurs the ordinary granitic gneiss merging into the muscovite biotite granite. The width of the granulite border varies from one or two feet to many yards. Where typically developed, it is a fine-grained, light-gray rock, and sometimes is pure white. At the contact, red garnets are abundant. When microscopically examined in thin sections it is found to be composed of a fine-grained aggregate of orthoclase, plagioclase, microcline, quartz, and muscovite, with garnets, limonite, some biotite, and iron pyrite. At several localities the granulite can be followed from the contact, and is seen to pass gradually into the ordinary granitic gneiss. The rock at first becomes coarser, loses its granulitic structure and assumes the granitic form. The garnets disappear and biotite becomes abundant, together with magnetite and limonite. Bands of the granulite occur cutting across the bedded slate. Often they are less than an inch in thickness, but connect with the main mass of the rock. Some of these small bands contain much muscovite and are well foliated. The intrusive, eruptive nature of the granulite is thus made apparent.

From Tewksbury, extending easterly along the southern bank of the Merrimac river for nearly a mile, there is a continuous outcrop of coarse mica-granite, in part gneissic, cutting slate that is greatly metamorphosed,

it now being a very hard, tough rock. The granite penetrates the slate parallel to its bedding, the strike being northeast to southwest and the dip 40° northwest. These steep rocks are locally known as "Deer Leap rocks," they being on a noted runway for deer in colonial times. North of these rocks there is an outcrop of quartz mica diorite. The exact contact is concealed by drift-sand and river silts. In the bed of a brook, near the boundary between Tewksbury and Andover, there is an outcrop of this gneiss having the same formation as that found at the Jones quarry in West Andover. From the strike of the outcrops it may be presumed that the bed-rock for this entire area is mica-granite, in some places becoming a granitic gneiss.

Southwest of Fish brook in Andover, on both sides of the river road, there are outcrops of a diabasic diorite, and other outcrops are to be seen on the westerly side of Wood hill extending nearly to "Deer Leap rocks." The Wood hill outcrop is an augite hornblende gabbro. This gabbro is identical in structure with the rock at the Dracut nickel mine.[1] Recent excavations for sewer pipes reveal this rock in South Lawrence, and it is probable that dikes and sills of this gabbro erupted into the foliated granite, produced the crushed arkose in the bottom of the Jones quarry at West Andover. Little or no tilting from the original foliation is seen in this quarry. The foliation is perfectly flat and horizontal until a depth of ten feet is reached, below which the rock is shattered and reconsolidated into a typical arkose, in which there are zones of a very fine basic slaty rock. The individual grains in these zones, when studied from thin sections with the microscope, appear to be parts of a crushed rock and not the usual rounded sedimentary water-worn grains. Probably at a greater depth than any excavation that has yet been made, some dike in the form of a sill has been forced through the gneissic granite parallel to its foliation and produced this crushed formation.

Between Bear hill and Lake Cochichewick, there are several outcrops of this granite about one fourth of a mile wide, extending into Boxford in a northeasterly course for about a mile. Outcrops also occur near Johnson's pond, in South Groveland. On widening the road opposite Lake Saltonstall, in Haverhill, a mass of granitic gneiss was uncovered for a length of over two hundred yards. It is probably a vein or dike of the mica-granite which is massive at the north, in Salem and Atkinson, N. H.

Paisanite, a granite porphyry dike rock with granophyric and micro-

[1] This ore contains only .0023 of one part of nickel.

pegmatitic tendencies, occurs below high tide in the small bay between Woodbury's point and Hospital point at Beverly. The trend is north 25° east. This outcrop, which was discovered in 1888, is about forty feet long and ten feet wide and is exposed at low water. The microscopical structure is as follows:

Quartz of two generations, a granular mass and also pyramids of quartz phenocrysts, is thickly scattered through the dark-gray ground-mass, together with phenocrysts of white feldspars. The feldspars are stout prisms. Hornblende and biotite, the former in microliths, are very abundant and pleochroic to a high degree from blue to yellow. Glaucophane crystals are also seen. The feldspars are microperthite and are filled with dust-like inclusions.

Fig. 67. — QUARTZ AUGITE SYENITE.
Poorhouse Hill, Beverly.

Fig. 68. — AUGITE SYENITE.
Dudley L. Pickman estate, Beverly Cove.

CHAPTER VII

THE SYENITE ROCKS

The syenite rocks of Essex County are igneous eruptives, and intrusives, in dike forms, the principal mass being of the granitic type. Many of the outcrops are very distinctive in form and of different textures and colors, due, in part, to the basic minerals in their composition. In the present work these rocks are divided into several distinct series.

Essexite, the type of one series of basic syenites, is the oldest form.

Salemite, a foliated basic type containing nepheline and augite.

Nepheline syenite, an acid rock containing nepheline.

Quartz augite syenite, or akerite, having no nepheline.

Pulaskite, having little or no nepheline.

Arfvedsonite mica syenite.

Ægirine syenite.

Hedrumite, having neither nepheline nor hornblende.

Nordmarkite, a mica hornblende quartz syenite.

Sölvsbergite, or Bostonite porphyry, a dike rock.

Biotite tinguaite, a dike rock.

Ægirine, or analcite tinguaite, a dike rock.

Camptonite, a dike rock.

Kersantite, a dike rock.

Umptekite, or hornblende gabbro, a massive basic rock associated with the syenites.

Keratophyre, a lava flow covering the aporhyolites on Marblehead Neck.

These types are subdivided into various forms. Essexite, for example, is a massive, slightly porphyritic rock nearly black in color, which contains nepheline without olivin. There is also a micaceous Essexite, having biotite in excess in the form of a ferro-magnesian mineral. Thirdly, an Essexite of a light-blue color, having little or no nepheline, and lastly, a foliated Essexite of light-blue color, having much nepheline. Umptekite, or hornblende gabbro, is a series in which the umptekite variety of hornblende is sometimes seen in large cleavable masses. Sometimes it is

found to be a mica hornblende gabbro with an excess of biotite over hornblende. In the larger part of the area where it occurs it shows about equal amounts of hornblende biotite and feldspar. This is the hornblende gabbro type of Professor Washington, found on Salem Neck. In connection with the dike rocks already enumerated there are at least twenty as yet undetermined which are probably members or apophyses of the main syenite mass.

An outcrop of akerite appears at Lynnfield, in the southwestern part of the County, in an old abandoned railroad quarry, south from Pilling's pond. An intrusive in the hornblende granite, without doubt it is a tongue extending from North Reading, where it is the principal rock of the region. From Lynnfield this tongue extends southeasterly to Wyoma lake in Lynn. Branches also reach into the hornblende granites of Peabody. This formation is augite syenite or akerite of Professor Washington. There are two forms: a quartz augite syenite (see Fig. 87), and a form without quartz, though sometimes it is microscopically present as intersertial blebs between feldspars. The quartz augite syenite outcrops along the shore between Beverly Cove and Gale's point, Manchester, in connection with hornblende granite and dike rocks. In a quarry on the estate of W. D. Pickman, at Beverly Cove, the typical augite syenite is found with little or no quartz. (See Fig. 88.) Other exposures are seen near the railroad station in Essex and also at Conomo point. East of the Magnolia railroad station the first ledge is augite syenite. Another outcrop may be seen near the poor-farm at Gloucester. These syenites occur in an area eight miles wide and twelve miles long, including the territory occupied by Marblehead, Salem, Beverly, Hamilton, Wenham, Essex, and Manchester. Another area occurs in Gloucester and Rockport and although not so great as the last, it contains a larger number of outcrops.

The Syenites of Salem Neck and Vicinity. — The oldest rocks in the area comprising Salem Neck, Winter island, and vicinity, are the sedimentary beds of slate and sandstone, both remnants of a series of Cambrian sediments. Next in order is the hornblende diorite, which is seen cutting these Cambrian rocks. Then follow the rocks of the syenite group in turn cutting and brecciating the diorite.[1] These syenites were erupted from beneath the older diorites, cracking them, and filling the openings with the syenite magma. (See Figs. 89, 90.)

[1] The author has plotted all the outcrops of bed-rock in this area, described in the following pages, upon a map drawn to a scale of 300 feet = one inch, and contemplates its early publication together with a paper on the geology of the locality.

Fig. 89. — BRECCIATED HORNBLENDE DIORITE CUT BY VEINS OF PULASKITE SYENITE.
Near Beverly Bridge, Salem.

Fig. 90. — HORNBLENDE DIORITE CUT BY VEINS OF PULASKITE SYENITE AND DIABASE.
Near Beverly Bridge, Salem.

At the contact of the pulaskite and diorite, there is a slight metamorphism of the minerals; the plates of biotite in the diorite are larger and more frequent, and greater masses of hornblende have been developed in the pulaskite than elsewhere. The remnants of the sedimentary rocks on Winter island and across the harbor on Naugus Head, are deeply metamorphosed from sandstones into a hard, compact quartzite. The slates have been transformed into mica-schists, and the limestones into chert, by the intrusion of diorites, syenites, and dike rocks.[1]

On Bentley's hill there is a dike in the form of a vein of pegmatite. Nepheline occurs in large, irregular masses, also hydronephelinite, and some radiated nepheline. Sodalite is also present in large, irregular blue patches, and zircon crystals, from 3 to 7 mm. in length, are not uncommon. East from this nepheline syenite outcrop, there is a wide exposure of hornblende gabbro which extends to the road. Across the road are outcrops of Essexite with little or no nepheline, and upon the hill is an outcrop of very coarse mica syenite, without nepheline, which cuts the hornblende gabbro.

There are exposures of Essexite on the shore of Collins' cove, southwest of the poorhouse, and eighteen different outcrops may be counted beside Fort avenue. From Fort Lee, for a distance of fifteen hundred yards, the outcrops are pulaskite syenite and hornblende gabbro. For the remainder of the distance to the wharf at the Willows, there are five outcrops of Essexite, hornblende gabbro, and nepheline syenite. In contact with the nepheline syenite is a mass of Essexite, south of which is a contact with hornblende gabbro. Proceeding southerly along the shore, the next outcrop is nepheline syenite with a hornblende gabbro contact. The trend of the outcrops of Essexite between Collins' cove and the wharf at the Willows, is northeast to southwest.

The hedrumite form of pulaskite is first seen on the north side of the poor-farm wharf and is continuous by outcrops on the Beverly harbor side for about fifteen hundred yards. The orbicular or hornblende syenite occupies a small area on the shore, nine hundred yards northeast of the poor-farm wharf.

The outcrops of bed-rock on Winter island are nearly all confined to the shore at Cat cove and the sea-shore on the other side of the island.

[1] Professor Brögger of Norway, who visited this locality May 30, 1900, considers this area of syenite rocks originally to have been in the form of a bathylitic structure, and that varying degrees of cooling and solidification of the magma produced the various groups or series of sheets, of unequal thickness, all chemically related to each other.

The first outcrop south of the causeway is hornblende gabbro, which extends for one hundred yards, and is cut by a porphyritic diabase dike twenty-five inches in width, having a trend north 20° east. Both are cut by pulaskite syenite veins. Continuing south, the next outcrop is hornblende gabbro cut by veins of pulaskite, beyond which is nepheline syenite for a distance of three hundred yards. At the point, there is a vein of hedrumite, six feet wide, which cuts the gabbro. On the next point, the outcrop is hornblende diorite, which is also found on the Hathorne farm on the Neck. Higher up on the ridge are two outcrops of the hornblende gabbro cut by veins of pulaskite. On the shore of Cat cove, fifty yards south of the diorite outcrop, there are two exposures of pulaskite syenite; and one hundred and fifty feet farther south, there is an outcrop of the gabbro rock. The next outcrop is diorite, and occurs on a small point. These outcrops of diorite and gabbro are brecciated by veins of pulaskite and nepheline syenite, the latter occurring in veins from one to six inches in width. The nepheline occurs in large blebs in the center of the veins. These outcrops, as well as the hornblende gabbro, are cut by narrow veins of pulaskite syenite. The gabbro extends to the point near the powder-house.

Near the powder-house on Winter island are exposures of Essexite, cut by pulaskite veins. Near-by a dike of porphyritic diabase, eighteen inches in width, runs parallel with the shore; and several small basic dikes of olivin basalt, from one to five inches in width, cut the other members of this group of rocks. Along the shore, between the powder-house and the lighthouse, there is an outcrop of hornblende gabbro two hundred yards in length. A small outcrop of pulaskite then follows, and is succeeded by a mass of diorite ramified by veins of gabbro and pulaskite. This diorite extends to the cove in front of the light-keeper's house. On the shore, near the center of the cove, there is an outcrop of Essexite and seventy feet distant, toward the south, dikes of gabbro and diorite are exposed, showing veins of pulaskite. One hundred and fifty feet north of the lighthouse are outcrops of Essexite cut by veins of pulaskite, and beyond is an outcrop of Cambrian slate and sandstone metamorphosed into a mica-schist, such as may be found at Naugus Head and also on the Marblehead shore. This slate outcrop extends to the northeasterly side of Fort Pickering. At the last angle of the fort, on the same side, are outcrops of diorite cut by veins of pulaskite, beyond which are veins of pulaskite cutting mica syenite. On the shore, in the valley northeast of the fort, there is an outcrop of orbicular or hornblende syenite, fifteen

Fig. 91.—SALEMITE, ON THE SOUTH SIDE OF FORT AVENUE, SALEM NECK.

Fig. 92.—ESSEXITE, CUT BY VEINS OF PULASKITE SYENITE AND CAMPTONITE, NORTH SIDE OF FORT AVENUE, SALEM NECK.

feet in width, in contact with nepheline syenite and a coarse mica-schist. Towards the northeast the contact is with hornblende gabbro. Three hundred feet of beach, composed of drift, then intervenes with two small outcrops of mica syenite and an outcrop of hornblende gabbro, ten feet in width, and is succeeded by an exposure of pulaskite, three hundred feet wide, and another of light-blue foliated Essexite, two thirds as wide.

At the point are outcrops of hornblende gabbro and pulaskite, and a hundred feet beyond is Essexite, which extends into Little Good harbor. On the south shore of Little Good harbor are exposures of nepheline and mica syenite extending to the inner point. Beyond is pulaskite, followed by other outcrops of nepheline and mica syenite, which continue to the causeway. On the north side of Little Good harbor, all the outcrops are hornblende gabbro cut by numerous dikes and small veins of pulaskite syenite, camptonite, diabase, and olivin basalt. A camptonite dike over two feet wide cuts across Juniper point from the southwest to the northeast. Running parallel is a large dike of diabase, in which the large feldspar crystals have become absorbed or eroded by the glassy groundmass, and left as round dots over the surface of the rock. Southwest from the Salemite outcrop on Salem Neck, all of the ledges are hornblende diorite, with some small areas of hornblende gabbro. Both are cut by veins of pulaskite syenite. This diorite is the bed-rock of the Hathorne farm and the "Point of Rocks," and continues westerly across Salem. Forms of the hornblende gabbro, with areas of diorite, comprise the larger number of the outcrops of bed-rock on Winter island, Salem Willows, and the area west of Fort Lee. There are also numerous dikes of diabase, olivin basalt, camptonite, and pulaskite syenite.

Essexite. — Essexite is a porphyritic rock and resembles porphyritic diabase, except that it contains nepheline. (See Fig. 92.) Its color is almost black. Another form of Essexite has a similar color, but is not porphyritic, and contains much biotite. Still another form is light-blue in color, and is fine-grained. The rock seems to be holo-crystalline, like a dike rock, but in reality it is a massive boss in the nepheline syenite area.

Microscopical examination of thin-sections of this rock shows that it is composed of augite, green and brown hornblende, biotite, plagioclase, and an abundance of titanite and rutile microliths, micro-zircons, and apatite. The porphyritic plagioclase crystals and also the hornblende areas are seen to have numerous patches of elæolite and perhaps sodalite, as inclusions in them. The sodalite being isotropic and both the minerals in the section, after treatment with hydrochloric acid and staining with fuchsin in water, show the plagioclase and hornblende to contain

numerous areas of these minerals which gelatinize. Some of the nepheline in these sections contains numerous feathery and fan-shaped zeolites that are probably natrolite. These are displacements of the decomposing nepheline. Everywhere on the surface this decomposition of the nepheline is seen changing the color of this mineral from an oily-green to a dull-lead color. The biotite is very fresh and of a red color. Granular masses of leucoxene surround grains of titaniferous magnetite, secondary products from the decomposition of this iron ore. (See Fig. 93.)

Salemite. — West from the Essexite group on Salem Neck is a mass of hornblende gabbro about ten rods wide (see Figs. 91, 107), cut by numerous veins and dikes of pulaskite syenite and basic dikes of camptonite. Extending from this gabbro is a low-lying outcrop of a foliated blue rock that is decidedly different in texture. It is much coarser, and contains considerable biotite, suggesting on the surface a biotite schist. A microscopical examination of thin sections of this rock shows it to be composed of the following minerals: hornblende, biotite, ægirine, olivin, titanite and leucoxene in the form of titaniferous-magnetite simple-twinned orthoclase, some plagioclase, having fine multiple-twinning and extinction of albite, nepheline, and sodalite with micro-zircons and apatite crystals in the feldspars. (See Fig. 94.) As this rock contains nepheline it therefore bears the same relation as the Essexites to the nepheline syenites. It is a basic rock and in this respect is similar in appearance to Essexite, save that it is foliated, but it varies decidedly from the Essexite in that it contains olivin, which would class it in the foyaitic series. For this foliated basic nepheline rock, the name Salemite is proposed, and has been used since 1896.

Associated with all of the other forms are masses and streaks which are foliated and schistose having all the appearance of crystallized sediments. That these masses are remnants of original flows in the then unconsolidated magma of the nepheline syenite is plainly evident by comparing them with certain well-known Cambrian crystalline sediments, such, for instance, as those at Naugus Head on the Marblehead shore, Woodbury's point on the Beverly shore, and the cove on the west shore of Great Misery island, which are cut by masses and veins of this syenite containing large inclusions and fragments of these Cambrian rocks with perfect outline. By these examples it will be seen at once that the former schistose rocks are totally unlike the latter, and could not be mistaken for them. Other causes of variation in these syenites are due in part to the acidic or basic quality of the magma at the time of cooling and crystallization.

On Salem Neck, at the right-hand side of the road to the Willows, there

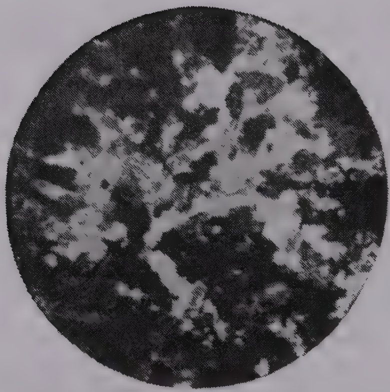


Fig. 93.—PHOTOMICROGRAPH OF ESSEXITE FROM SALEM NECK.

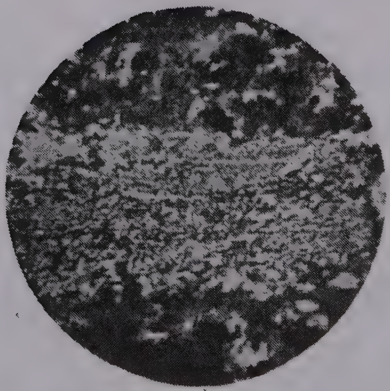


Fig. 94.—PHOTOMICROGRAPH OF SALEMITE FROM SALEM NECK.

is an outcrop of Salemite in a field near a small pond. The rock is dark-gray to bluish in color, and has a granitic structure. The outcrop is only twenty feet long and ten feet wide, and in the center the structure is foliated or schistose, the outer portion being quite massive without any foliation. The microscopical structure is as follows:

Augite, ægirine, brown hornblende, red mica, hornblende, var. arfvedsonite, orthoclase, and a plagioclase that has the fine multiple-twinning of albite. Sodalite, nepheline, some titaniferous magnetite, apatite, and micro-zircons. These minerals are in elongated and rounded grains, with biotite plates formed in the line of the schistosity of the rock-mass. The large feldspars are in nearly perfect crystals, and are honeycombed and filled with elongated and rounded grains of the ground-mass which has punctured the crystals. One good basal section of apatite has a fine bubble inclusion, and also inclusions of original glass. Many of the simple-twinned feldspars are perthite. Some of them have a brecciated structure, having been punctured by the ground-mass. Much of the nepheline is interstitial.

Nepheline Syenite. — Nepheline syenite is an acid rock containing nepheline. In any typical outcrop, forms will be found in the rock-mass which are clearly due to local variation. The type is a coarse feldspathic rock, in which the nepheline and sodalite are seen in large blebs and patches with numerous macroscopic zircon crystals, some of which are one fourth of an inch long, with perfect double pyramidal facies. (See Fig. 96.) In thin section, when studied with the microscope in polarized light, the feldspars are seen to be composed:

First, of large, irregular crystalline intergrowths of microline and albite, and second, of areas of orthoclase with occasional crystals of well-twinned plagioclase, probably Labradorite. The orthoclase is often filled with microliths of a dust-like character. In close proximity to the zircons, rhombic sections are often seen of a mineral of a yellowish-green color which is isotropic, and as yet is undetermined. There are also occasional crystals and grains of ægirine which show a pleochroism varying from blue-green to a yellowish-green, and, with the quartz wedge as determined by the negative bisectrix, make an angle of 4° or 5° with the vertical axis. Some augite is present, showing brilliant colors in the basal section, also brown hornblende, much perfectly red biotite, and some magnetite. In the microscopic investigation of loose grains, the specific gravity of the minerals of the crushed rock, when passed through the 90 mesh sieve and separated in the Thoulet solution, gives the following portions as determined by the Westphal balance: Specific gravity 2.75 separated the mica hornblende, augite, zircon, and magnetite; 2.726 removed some remaining scales of biotite with Labradorite; 2.614, elæolite, plagioclase, and albite; 2.595, microcline and albite, which forms the largest proportion of the crushed rock; 2.585, orthoclase and microcline, leaving sodalite and orthoclase as the residue.

Outcrops of nepheline syenite occur on Salem Neck, south and east of the pest-house, and extend to Fort avenue. Other outcrops appear on Winter island. Great Haste rock is largely composed of this formation, and on Misery island, outcrops appear on both sides of "the harbor," and also on the eastern side of the island, north of the outer cove. On the western side of the island, there are eleven outcrops, and on the extreme southeastern point is an outcrop in which nepheline and sodalite occur.

Quartz Augite Syenite or Akerite. — The determinations of the minerals in this rock, studied in thin sections with the polarizing microscope (see Fig. 97), are as follows: Orthoclase, brown hornblende, red mica (probably phlogopite), much titanite, numerous fine sections of augite, several small crystals of apatite, a few small zircons, one section of microcline in one of the slides, Baveno twin-crystals of orthoclase which show the intergrowth of albite as microperthite. The augite is often surrounded by magnetite, and dust-like inclusions of magnetite in the orthoclase give this syenite its dark color. In some of the sections from the outcrop at Prospect street, Gloucester, there are some quartz blebs, but the rock as a whole is poor in quartz, and resembles the syenites of Charnwood, England.[1]

Augite syenite outcrops beside the road, south of Hawkes' brook in South Lynnfield, and occasional outcrops may be seen for about one half of a mile, on both sides of Salem street.

In the Robin Rock granite quarry, South Lynnfield, the rock-mass is a typical hornblende granite, but the rock in the older part of the quarry at the south side is without quartz, and is therefore a form of augite syenite. Between Wyoma and Mount Spicket in the Lynn woods, are numerous exposures of quartz augite syenite, which extend to the northern end of Wyoma lake. Dikes of syenite, six to ten inches in width, cut the diorite in the western part of Salem. These dikes resemble an akerite syenite but without quartz. Such a dike outcrops on a high diorite ledge over a mile from Salem Neck. The highest points in the County where the syenite rocks occur are Briscoe hill and Poorhouse hill in Beverly. On Briscoe hill the rock is a coarse akerite at the east and south, and a nepheline syenite at the west. Poorhouse hill is a quartz hornblende syenite.

A mile west from Curtis' point, Beverly, are outcrops of augite syenite. Outcrops are also numerous in Montserrat woods, southeast from the Salem reservoir hill. There is also an exposure on the Beverly shore,

[1] Quarterly Journal of the Geological Society, Vol. XXXIV, p. 215.

Fig. 95. — BIOTITE TINGUAITE DIKE IN AUGITE SYENITE LEDGE, MANCHESTER.

Fig. 96. — NEPHELINE SYENITE WITH VEINS OF PULASKITE AND HORNBLENDE GABBRO · ALSO SHOWING EROSION OF BOULDERS *IN SITU*.
Cat Cove, Salem Neck.

fifty yards east of Mingo beach, which extends to Tuck's point and northerly to a large outcrop south of Beverly common. On Briscoe hill the rock is a coarse augite syenite, cut by veins of pulaskite. Outcrops occur in the Hale Street cemetery and on Poorhouse hill. On Corning street, Beverly, are other outcrops of the same rock.

Bald hill, Beverly, is composed entirely of augite syenite, in various forms, coarse and fine. The microscopical structure of several of the above named outcrops is as follows:

Thin sections prepared from specimens collected in an old quarry on the W. D. Pickman estate at Beverly cove: numerous large porphyritic crystals of microcline-microperthite[1] (see Fig. 98), some multiple-twinned plagioclase, probably Labradorite, much orthoclase, augite in two forms, one in large, ragged crystals, and the other in long, needle-shaped crystals inclosed in the feldspars as microliths, numerous small, ragged crystals of ægirine, some brown hornblende, red biotite in large patches, numerous perfect zircon crystals, fine sections of nepheline, some apatite and magnetite, with a ground-mass of thin films of quartz.

Sections prepared from the outcrop on the east side of Briscoe hill, in Beverly, are of similar composition, but contain, in addition, olivin and titanite. At the ledge used for road-building purposes on Poorhouse hill, there are two well-marked forms. One is rich in hornblende, contains little augite and has much quartz, not only as a ground-mass, but also as distinct patches, with fine, large crystals of microcline-microperthite (the soda-microcline of Professor Brögger), some ægirine crystals, apatite and magnetite. The other is rich in augite, has considerable quartz, some hornblende, biotite, ægirine, and nepheline. The first, except for the ægirine and microcline-microperthite, would be classed as hornblende granitite. The other is nearly if not quite like the typical augite syenite. In this last a vein of pyrrhotite of a rich yellow-bronze color is seen, which carries a small percentage of nickel. Molybdenite also occurs in this outcrop.

North of Long hill, Manchester, are several outcrops of augite syenite, and one opposite the West Parish meeting-house, Gloucester, is quite basic and schistose. A blue pulaskite outcrops opposite the store of William Rust, and farther west on the Essex road other outcrops may be seen. All of the exposures west of Haskell's mill brook, from Lufkin street to the shore at Conomo point, are augite syenite, which is also the bed-rock of Cross' island. From Conomo point to the Essex town-farm, all the outcrops are of the same character, in fact, this is the prevailing rock from Coy's pond in Wenham to Thompson's village in South Essex.

Southeast of Moses' mountain in North Yarmouth, Manchester, the outcrops are quartz hornblende syenite, in which the hornblende is a form

[1] This form of feldspar is characteristic of Professor Brögger's microcline-microperthite in the augite syenite rocks of Norway. — Brögger, Min. der Syenite Py., p. 627.

of arfvedsonite. The ledge used by the town for road material in 1899 is the same rock. From Lobster cove to Gale's point, and northerly into Manchester harbor, all the outcrops are syenite, largely akerite and ægirine syenite. The Ram islands, Chubb's island, and House island are augite syenite. On the higher part of Misery island, on the west side, is an outcrop of nordmarkite with wide dikes of sölvsbergite. On the shores of the island are numerous basic dikes cutting the more massive rock of the island.

Within the city limits of Gloucester, bounded on the north by Warner street, and extending several hundred yards on Prospect street, to the south and southwest, is a large mass of augite syenite. Occasional outcrops are also seen south of this in East Gloucester, near Bass rocks, and in the cove in Gloucester harbor west of Ocean pond, which embraces the larger part of Eastern point. In a westerly direction, there are outcrops near Goose cove, Annisquam. One large, dome-shaped mass near the corner of Quarry street, Bay View, is of a coarser texture and greener in color, and resembles the augite syenite of Essex and Manchester. From this last-named outcrop to the northeast side of Plum cove, Lanesville, there are numerous exposures in old, deserted quarries, and one especially good section is seen by the roadside opposite Young avenue, Lanesville. The trend or strike of all of the outcrops is in the usual direction, N.N.E. to S.W.

This entire outcrop is some twelve miles long, and from a few rods wide in Hamilton to six miles in Essex and Manchester, the latter width continuing across Gloucester from Lanesville to Eastern point. A massive ridge of augite syenite extends from opposite Rocky neck to Bass avenue, and also outcrops at the cove near Niles' pond. At Wonson's cove and at Smith's cove this syenite is exposed below the road wall, where it is surrounded by beach sand. The feldspar crystals are large and very perfect, giving the surface of the outcrops a porphyritic appearance. The bedrock on Warner street is an augite syenite in appearance, but megascopically it resembles ægirine syenite at Gale's point, Manchester. This form is entirely distinct from the quartz augite syenite on Prospect street.[1] A massive outcrop of syenite occurs near Dike street, and is used for road material. It is deep blue in color, and is identical with the blue pulaskite of Professor Williams. Another outcrop of this rock may be seen in the railroad cutting east of the Magnolia station. In the area between Fresh-

[1] The Petrological Province of Essex County, Journal of Geology, Vol. VI, p. 789.

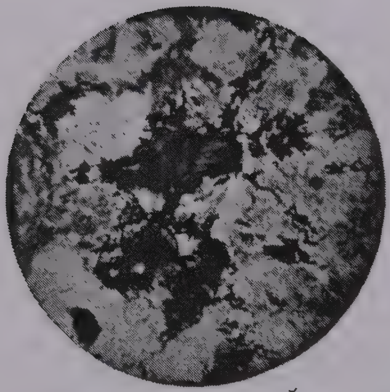


Fig. 97.—PHOTOMICROGRAPH OF AUGITE SYENITE, OR AKERITE.
South Salem.

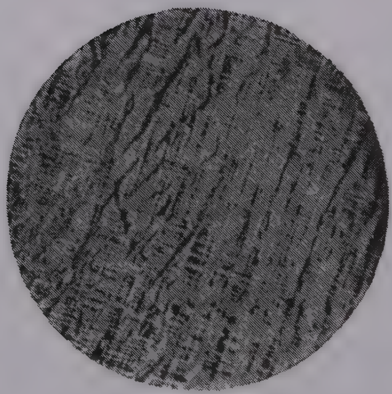


Fig. 98.—PHOTOMICROGRAPH OF MICROCLINE CRYSTAL AUGITE SYENITE FROM BRISCOE HILL, BEVERLY, SHOWING ALBITE INTERGROWTHS ACROSS THE TWINNED MICROCLINE.

water Cove village, Gloucester, and extending southwesterly to the Magnolia station, the outcrops of augite syenite are one half of a mile wide.

At the augite syenite outcrop in Brace's cove, East Gloucester, and by the roadside on the sand-beach near the Niles' farm buildings, on the southwest side of Eastern point, the large, almost perfect, tabular feldspar crystals give this rock a very striking appearance. The microscopic structure of thin sections, when studied with the polarizing microscope, shows the following minerals in its composition:

Much augite, green hornblende, glaucophane and chlorite as secondary products in the decomposition of the hornblende, microliths of ægirine, one characteristic crystal of hypersthene, magnetite, limonite, numerous zircon and apatite crystals, orthoclase, microcline-microperthite, some plagioclase, and a little quartz as the ground-mass. The large tabular porphyritic crystals of feldspar are microcline-microperthite. The outcrop of this augite syenite, in the marsh near the poor-farm, used by the city of Gloucester for road-making, is of a very dark color, and a macroscopical examination would indicate it to be diorite, but the microscopical structure, as seen in thin sections, shows it to be composed of augite, ægirine, hornblende, limonite, some biotite, orthoclase, microcline-microperthite, zircons, apatite, magnetite and a little quartz as a cement in the ground-mass, making the rock a typical augite syenite. Numerous thin sections have been prepared from all parts of the outcrops of this augite syenite described above. In specimens from the corner of Warner and Prospect streets in the city of Gloucester, the microscopical structure is quite characteristic of this rock-mass. They all contain augite, ægirine, titanite, microcline-microperthite, with some quartz. Some of the sections contain nepheline, and one section contains an excess of the fine multiple-twinned albite (sp. gr. 2.63). There is more or less orthoclase, hornblende, biotite, and magnetite with crystals of zircon and apatite as inclusions in the feldspars.

Several thin sections of the rock in the massive outcrop near Magnolia station, and in the railroad cutting one hundred yards east of the station, when studied with the polarizing microscope, were found to be composed of microcline-microperthite, well-twinned plagioclase, orthoclase, augite, green hornblende, red biotite, zircons, apatite, fine sections of titanite, much magnetite, some limonite, nepheline and isotropic sections of sodalite which gelatinized readily with hydrochloric acid. Some sections also contained regular crystals of hypersthene and some well-formed crystals of olivin. In one of the sections there were large patches of elæolite. The

color of the whole rock-mass in fresh hand specimens is dark grayish and green. This rock is quite distinct from any member of the nepheline-zircon-syenite group heretofore described, inasmuch as it contains hypersthene and olivin without a glassy ground-mass, and it is equally distinct from the typical augite syenite of Vom Rath.

On Main street, Lanesville, opposite Young avenue, is an outcrop of augite syenite, and other outcrops fringe the shore from Annisquam to Squam harbor. Sections from the Lanesville outcrop, opposite Young avenue, contain olivin. In some of the sections, serpentine has developed in the cleavage cracks, and some of the feldspars have the microscopical characters common to anorthoclase, extinguishing by sections and in patches. This is the soda-microcline of Professor Brögger.[1] One section shows multiple-twinned albite intergrowths directly across the twinned microcline, giving it a very beautiful appearance when seen in polarized light. There are also numerous irregular fragments of ægirine and a few small, triangular patches of nepheline with a ground-mass of quartz as a cement. Several interesting dikes in this vicinity cut the granite and syenite rocks. A sölvsbergite dike at Andrews' point cuts hornblende granite, and a third of a mile east from Squam lighthouse are several wide dikes of tinguaite and quartz syenite porphyry. Within two hundred yards of the light, there is a biotite tinguaite dike.

Dikes and masses of Labradorite gabbro occupy the greater part of Davis' neck, Bay View. It is a very conspicuous rock with crystals of Labradorite, some of which are two inches wide, and from three to six inches in length.

The Dry Salvages or Tri-Salvages, and the Little Salvages, islands east from Sandy Bay, are outcrops of hornblende syenite having little or no quartz. The larger number of the outcrops on the north side of Gap Head and Straitsmouth island are syenite, with some areas of micrographic granite. In a southwesterly course from Gap head to the Rockport pumping station, extending on both sides of Cape pond, all the outcrops are augite syenite.

From Bass Rocks, Gloucester, to Cobblestone beach, the outcropping bed-rock is quartz syenite, porphyry, and aplite. From Brace's cove, westerly across Eastern point to East Main street, all the outcrops are augite syenite. Thatcher's island has about eighty acres of surface, and is a massive outcrop of augite syenite cut by several basic dikes. The augite syenite outcrops at Emerson's point on the mainland opposite the

[1] Zeitschrift für Krystallographie, Vol. XVI, p. 261.

Fig. 99.—PULASKITE SYENITE FORMED INTO BOULDERS *IN SITU* BY DISINTEGRATION AND EROSION.
Salem Neck

Fig. 100.—PULASKITE SYENITE VEINS CUTTING DECAYED HORNBLENDE GABBRO.
Salem Neck.

island, and also on the north shore of Loblolly cove. Probably this akerite bed-rock is continuous under the sea from the mainland to Thatcher's island.

Pulaskite. — This formation varies from the augite syenite or akerite in that it contains little or no nepheline. (See Figs. 99, 100.) In some places, noticeably in outcrops on the Beverly shore at Curtis' point, it becomes distinctly a hornblende zircon syenite. Here the feldspars are microperthitic intergrowths of albite and plagioclase, with a large proportion of magnetite. Still farther to the eastward, along the coast, at Gale's point on the Manchester shore, occur veins of syenite rock, from a few inches to two feet in width, which the author has described as ægirine syenite, for these veins are completely filled with acicular ægirine crystals, some of which are two inches long and one-sixteenth of an inch wide. The feldspar in this rock has the optical character of anorthoclase. North of Fort Lee, on Salem Neck, the pulaskite becomes slightly massive in a ledge which was opened during the construction of the fort. West from this opening are two exposures of pulaskite, having little or no hornblende. On the Beverly shore from Mackerel cove to Woodbury's point, the syenite rock is largely pulaskite and a coarse akerite. Beyond the point, the outcrops are pulaskite, and extend to the western end of West's beach.

Nordmarkite. — This is a mica hornblende quartz syenite rock, and was so named by Professor Henry S. Washington of New Jersey. Its microscopical structure shows augite syenite minerals, microcline-microperthite, and the soda-microcline, which are characteristic minerals described by Professor Brögger as occurring in the augite syenite rocks of Norway.

There are outcrops of this rock on both sides of Lobster cove, Annisquam, extending for a third of a mile. It is also massive in West Gloucester, with many large outcrops. (See Figs. 101, 102.) The trend of the outcrops from Essex avenue, West Gloucester, to Lobster cove, Annisquam, is northeast to southwest, which is parallel to the prevailing strike of the sedimentary beds. A narrow vein of nordmarkite extends southerly near the creek by Essex avenue, beyond the railroad track, and an outcrop may be seen near the cellar of the Russia Cement works. The southeastern extension of this rock is seen in large outcrops on both sides of the railroad near the Anchor Forge and Iron Works, and on Rocky Neck, East Gloucester.

Thin sections prepared from specimens collected on Pierce's island in Squam river (see Fig. 103), have the following mineral composition: Nos. 1, 2, 3, contain numerous patches of red biotite, hornblende, and augite, in perfect crystal form,

microcline, orthoclase, microcline-microperthite, and numerous inclusions of zircons, apatite, and magnetite, the whole cemented in a ground-mass of quartz. Thin sections prepared from specimens collected in an old and deserted quarry on the northeast side of this island are much more porphyritic. The larger crystals are always microcline-microperthite (sp. gr. 2.60 to 2.64). One of the sections has fine crystals of titanite, and the quartz is in thinner films as a ground-mass or cement, otherwise the minerals are of a similar character to Nos. 1, 2, 3. Sections from an outcrop by the side of the road leading to Coffin's beach, near a deserted quarry in West Gloucester, are of a fine-grained rock, slightly porphyritic, with an abundance of biotite, perfect well-twinned crystals of albite, much microcline in large, irregular patches, microcline-microperthite, hornblende, augite, and titanite, some of the orthoclase feldspars having areas of micropegmatite. From the great abundance of biotite in this rock-mass it may be locally called a biotite nordmarkite (sp. gr. of feldspars in this rock, 2.57 to 2.62). Thin sections from the augite syenite outcrop at Wheeler's point, Gloucester, and extending to Goose cove, Annisquam, and Bay View, give the microscopic structure as follows: Nos. 1, 2. Wheeler's point, numerous large porphyritic crystals of microcline-microperthite, albite and orthoclase, good crystals of augite, hornblende, numerous crystals of titanite, some biotite, magnetite, a little quartz, some crystals of apatite and zircons. No. 3, section from Goose cove, is the same as the last. Nos. 4, 5, 6, sections from Bay View quarries, contain augite and ægirine. In one section, No. 5, there is a complete felting of these ægirine crystals which sink to the finest dust as inclusions in the microcline-microperthite, giving the rock a deep green color.

Sölvsbergite. — The Bostonite porphyry (Rosenbusch) on Coney Island, is known now as sölvsbergite, the name having been first applied by Professor Henry S. Washington of New Jersey. Naugus head, on the Marblehead shore, is largely composed of metamorphosed Cambrian sedimentary rocks cut by veins and large dikes of pulaskite syenite and sölvsbergite, which extend to Peach's point and Orne's island.

Coney island and the Coney island ledges are largely composed of a coarse pegmatitic mass of microcline-microperthite in which the albite equals the microcline in volume. There are also coarse plates of biotite and small zircons, the latter held as inclusions in both the soda-microcline and the biotite. Pulaskite syenite and hornblende gabbro, with numerous dikes, are also present. A large dike of vesicular basalt, the vesicles being filled with crystals of epidote, cuts across the island from northwest to southeast. Other interesting dikes, not yet determined, cut the pulaskite and gabbro rocks.

Great Haste rock and the Haste ledges are nepheline syenites containing nepheline, sodalite, zircons, and much titaniferous magnetite.

A dike of sölvsbergite, cutting the hornblende granite at Andrews'

Fig. 101.—NORDMARKITE LEDGE BROKEN DOWN BY ACTION OF FROST.
West Gloucester.

Fig. 102.—QUARRY OPENED IN A LEDGE OF NORDMARKITE, SHOWING IRREGULAR JOINTING OF THE ROCK. WEST GLOUCESTER.

point, the northeastern extremity of Cape Ann, has been analyzed by Professor H. S. Washington as follows:

SiO_2	64.28
TiO_2	0.50
Al_2O_3	15.97
Fe_2O_3	2.91
FeO	3.18
MnO	traces
MgO	0.03
CaO	0.85
Na_2O	7.28
K_2O	5.07
H_2O ig.	0.20
	100.27

Specific gravity, 2.703 at 22° Cent.

Biotite Tinguaite. — At Manchester, on Gale's rocks, two hundred yards south of Gale's point, near low-water mark, there is a dike of a very peculiar color. (See Fig. 95.) It is six inches wide, and is exposed for twenty feet. It cuts the augite syenite in a nearly horizontal position six feet below the surface of the syenite mass. This outcrop is only exposed to view at low water. On the surface the color is a grayish-green, mottled with bluish-black spots. A freshly broken surface is of an olive-green color, and the spots are black. Its occurrence in the immediate region of the ægirine tinguaite dike at Pickard's point and the ægirine syenite at Gale's point, attaches to this rock a special interest. A microscopical examination gave the following minerals in its composition: ægirine, nepheline, sodalite, biotite, a triclinic feldspar, microperthite, and some larger feldspars that gave optical characters suggesting anorthoclase, and having nearly the same structure as the anorthoclase phenocrysts in the keratophyre rock from Marblehead harbor. The black spots in the rock were magnetic iron, a decomposition product of an original biotite. Dr. A. S. Eakle of Harvard University made the following microscopical and chemical analysis of the rock:

The rock is composed mainly of feldspathic laths and plates with much nepheline and less amounts of ægirine, magnetite, and biotite. A little sodalite, apatite, and zircon are also present. The feldspars have a fibrous appearance caused by lamellar intergrowths of the soda and potash feldspars, microcline and albite, forming microcline-microperthite. Carlsbad twinning of the laths is common. Nepheline occupies the position of

a filling matter in the interspaces formed by the feldspars. The nepheline has altered, and is present as grayish, muddy, granulated sections, which are apparently mixtures of nepheline with kaolin and very fine grains of quartz. Ægirine is disseminated in the rock in fragments and small crystals, in sufficient amount to give it its greenish cast, shading from deep grass-green to an almost colorless appearance. Magnetite is prominent, and marks the remains of rather large plates of a former dark silicate. Most of the original silicate has completely disappeared, leaving only the patches of black oxide of iron; but in an occasional section, a greenish-brown silicate still remains between the black borders of magnetite, which from its absorption, parallel extinction, and characteristic shimmer, is evidently biotite. Sodalite is present, and also a few small crystals of apatite and zircon as inclusions in the feldspars.

The tinguaite dike at Pickard's point, Manchester,[1] contains much analcite, and is classified as analcite tinguaite. Very little isotropic mineral occurs in the dike here described, and from its appearance and the presence of chlorine, what is present is judged to be sodalite, so the dike can hardly be classed with the one at Pickard's point. The structure of the rock also differs in that the component minerals do not occur in needle forms, but in much stouter lath-shapes, showing a greater degree of crystallization of the individual minerals, and producing a much less dense phase of tinguaite. The presence of many plates of feldspar tabular to M indicates an approach to a sölvsbergite, and the rock might perhaps with equal right be considered a phase of a nepheline sölvsbergite. It seems in structure and composition to lie intermediate between a nepheline tinguaite and a nepheline ægirine sölvsbergite. The analysis of the rock yields:

SiO_2	60.05
TiO_2 and ZrO_2	0.11
Al_2O_3	19.97
Fe_2O_3	4.32
FeO	1.04
MnO	0.79
CaO	0.91
MgO	0.23
K_2O	3.24
Na_2O	7.69
H_2O at 110	0.15
H_2O ig.	1.26
Cl	0.28
	100.04

[1] Bulletin of Essex Institute, Vol. XXV, p. 4; and American Journal Science, Vol. VI, p. 176.

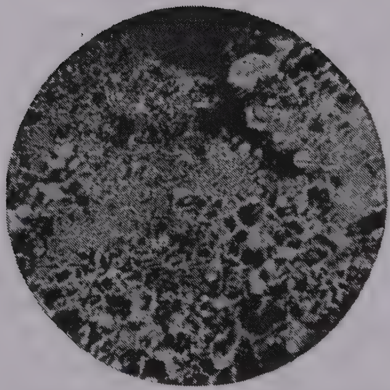


Fig. 103.—PHOTOMICROGRAPH OF NORDMARKITE, GLOUCESTER.

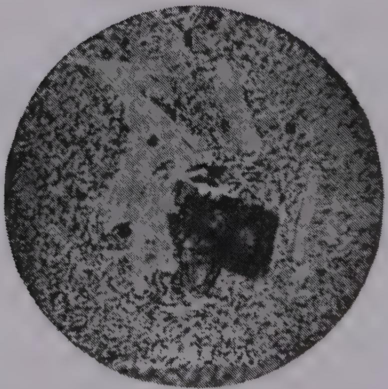


Fig. 104.—PHOTOMICROGRAPH OF ÆGIRINE TINGUAITE FROM PICKARD'S POINT, MANCHESTER.

The specific gravity is 2.708. The dike is difficult to reach, and the specimens examined come from near the surface and have altered enough to make it difficult to estimate the mineral contents with any degree of accuracy.[1]

Ægirine Tinguaite or Analcite Tinguaite. — Thin sections of this phonolite dike rock, when studied under the microscope in polarized light (see Figs. 104, 105, 106), show that it is composed of some crystals of sodalite, hexagonal in outline, and numerous long, irregular feldspar phenocrysts, which sometimes are in Carlsbad twins with a quite fine multiple-twinning and in one section there is double-twinning of the microcline structure. Several of the feldspar crystals have a perfectly square cross-section which is very noticeable, and suggests a resemblance to anorthoclase phenocrysts. Micro-chemical tests of this feldspar in hydro-fluosilicic acid give, upon evaporation of the acid, equal numbers of crystals of sodium (Na_2O) and potassium (K_2O), but with no calcium (CaO); specific gravity 2.572 to 2.58. The analysis of the anorthoclase feldspars in the keratophyre rock which was made at the laboratory of the United States Geological Survey at Washington, by Dr. Thomas Chatard, gave K_2O, 6.98; Na_2O, 6.56. This micro-chemical test, therefore, shows that the feldspar in this phonolite rock is very near if not chemically equal to anorthoclase. The hexagonal outlines of the sodalite phenocrysts are isotropic, and the mineral gelatinizes readily with acid, which upon evaporation gives an abundance of common salt crystals. There are also some crystals of green augite and brown hornblende, one of the outline hornblende crystals being filled with minute crystals of ægirine. The holo-crystalline ground-mass is composed of feldspars and feebly polarizing nepheline in a nearly complete felting of ægirine crystals and grains, some of which sink to the finest dust. These ægirine grains are so abundant in the feldspars of the ground-mass that the specific gravity of the feldspar in the rock-powder, even after passing through the 100 mesh sieve, could not be clearly made out, but with the inclusions of ægirine it was as low as 2.59. This rock-powder, gelatinized readily with acid, and, upon evaporation, an abundance of gypsum crystals appeared, thus characterizing some of the minerals in the ground-mass as belonging to the haüyne group.

A chemical analysis by Dr. Henry S. Washington gave the following result:

[1] Bulletin of Essex Institute, Vol. XXIX, p. 58.

SiO_2	56.75
TiO_2	0.30
Al_2O_3	20.69
Fe_2O_3	3.52
FeO	0.59
MgO	0.11
CaO	0.87
Na_2O	11.45
K_2O	2.90
Cl	0.28
H_2O 110°	0.04
H_2O 110° +	3.18
	100.68

Specific gravity, 2.474 at 22° Cent.

Umptekite Gabbro. — On Salem Neck, the Beverly shore, and on Misery island, are masses and dikes of a hornblende gabbro which varies greatly in structure (see Figs. 107, 108) In the same dike, or general mass, three different types have been found with various intermediate grades. First, a compact, tough, bluish-white, feldspathic mass containing a few grains of hornblende. Second, a crystalline rock composed of nearly equal amounts of feldspar, hornblende, and titaniferous magnetite. Third, a rock in which the feldspar becomes subordinate, serving merely as a matrix to hold large porphyritic crystals of hornblende, some of which are six inches long and three inches wide. From an analysis made by F. E. Wright, under the direction of Professor Rosenbusch of the University of Heidelberg, this hornblende mineral was shown to be umptekite. The chemical analysis was as follows:

SiO_2	62.99
Al_2O_3	14.25
Fe_2O_3	2.78
FeO	5.15
MgO	1.30
CaO	2.72
Na_2O	4.86
K_2O	6.35
H_2O + / H_2O −	0.18
TiO_2	0.16
MnO	0.18
	100.92

Specific gravity, 2.732.

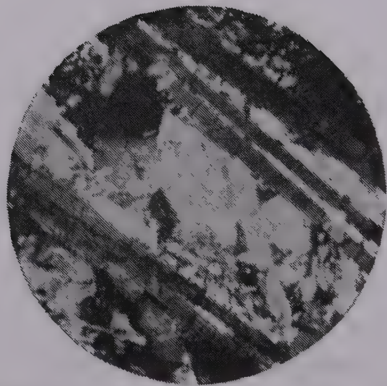


Fig. 105. — PHOTOMICROGRAPH OF ÆGIRINE SYENITE FROM GALE'S POINT, MANCHESTER. SHOWING THE ÆGIRINE CRYSTALS ARRANGED IN A PLANE WITH ORTHOCLASE.

Fig. 106. — PHOTOMICROGRAPH OF ÆGIRINE SYENITE FROM GALE'S POINT, MANCHESTER.

The rock-mass in which this umptekite form of hornblende occurs may therefore be called umptekite gabbro.

On Salem Neck, near Collins' cove, there is an outcrop of umptekite gabbro, varying from exceedingly coarse- to very fine-grained forms, greatly differing in portions of the same mass and making three distinct types.

Microscopic structure: No. 1. Orthoclase with fine zonal structure, some plagioclase with very coarse twinning, a little hornblende with inclusions of augite, much biotite, with zircons that show pleochroic halos, much magnetite, and a few apatite crystals scattered through the orthoclase.

No. 2. Large masses of brown hornblende, some augite, much biotite and magnetite, some plagioclase, a little orthoclase and apatite and zircons as inclusions in the biotite.

No. 3. Orthoclase somewhat kaolinized, a little plagioclase, hornblende, augite, and biotite. The augite is very fresh, and numerous good basal sections are seen in the field. There is also much magnetite, some micro-zircons, garnets, and apatite inclusions in the biotite.

Umptekite gabbro from Salem Neck and vicinity in the nepheline syenite belt has the following microscopic structure when studied in thin sections in polarized light. (See Figs. 109, 110.)

No. 1. Hornblende or umptekite gabbro: Numerous well-twinned plagioclase crystals, some orthoclase, green hornblende, an abundance of perfectly fresh biotite, crystals of olivin, some irregular patches of quartz, and some glassy plagioclase as inclusions in the biotite and hornblende. Some of the olivin is inclosed in these hornblende masses, and is much altered, forming magnetite. Numerous lime-iron garnets and cubical iron pyrites are also seen as inclusions in the plagioclase. Crystals of apatite and micro-zircons are abundant in all parts of the section. The specific gravity of the plagioclase is 2.69.

No. 2. Salem Neck. Hornblende or umptekite gabbro: Much green hornblende, good sections of augite, some olivin, large patches of biotite, fine well-twinned plagioclase, some orthoclase, a little quartz, numerous masses of quite large apatite crystals and a few zircons. Some of the olivin is partly altered to magnetite and serpentine.

No. 3. Salem Neck. Hypersthene umptekite gabbro: Much plagioclase, some orthoclase, hypersthene, augite, olivin, hornblende, biotite, and a little quartz. Otherwise as in No. 2.

On the northeastern side of Woodbury's point, Beverly, a dike-like mass cuts the pulaskite syenite and Pre-Cambrian schistose rocks, and is principally composed of umptekite with some brown hornblende, with biotite developed on the edge of the hornblende. The umptekite occurs in rectangular to irregular blocks or large crystal forms which are easily

cleavable. Occasionally a piece is found which is nearly a perfect cube some two inches square. Usually the feldspars are in large, felty masses of a bluish-white color, and are much decomposed, but in some places still showing the multiple-twinning of anorthite. Magnetite occurs in large, irregular crystal masses surrounding the umptekite.[1]

The same rock occurs on the southwest side of Great Misery island, and thin sections give the same microscopical character, except that the orthoclase and plagioclase are much fresher.

Keratophyre. — This formation (see Fig. 111) may be seen at low tide near the residence of Mrs. Harding on Boden's point, Marblehead Neck. It appears as the much eroded remains of a surface flow, and extends two hundred yards in a northeasterly direction, with a width of sixty feet at the lowest point of observation. There are smaller masses of this rock three hundred yards from this point in the same strike (northeast), which are exposed only at extremely low tides. About five hundred yards south of Boden's point near Flying point, the eruptive granite cuts the metamorphic slate, and near this point also the granite is cut by dikes of quartz-porphyry (felsite). Near the keratophyre, and dipping under it, is a banded aporhyolite. Both the granite and the felsite are cut by diabase dikes. The aporhyolite tends to the northeast and forms the larger portion of the bed-rock of the Neck. The banding of this aporhyolite dips towards the harbor nearly north, and lying upon it is the keratophyre. Between the lowest points of observation and the banded aporhyolite, a conglomerate of varying thickness composed of fine felsitic débris, holding rounded and angular fragments of the aporhyolite, is found in several places inclosed in the keratophyre. In some places the keratophyre rests directly upon the aporhyolite, while in others the conglomerate intervenes between them. The line of contact between the keratophyre and the rhyolite débris is well marked, and specimens detached at this point show a basal surface very rough and pitted where it conforms to the irregularities of the conglomerate. The rock is much decomposed on the surface, but the least altered specimens obtained are of a brownish or bluish-gray color, having a conchoidal fracture and a compact ground-mass, holding, occasionally, large, glassy crystals of anorthoclase, some of which are one-fourth of an inch in length, and, rarely, plates of biotite.

Microscopical analysis shows the ground-mass to be filled with lath-shaped feldspar crystals, which are somewhat decomposed. The base is an earthy kaolinized mass, with irregular masses of quartz and earthy

[1] Min. Pet. Mitth., Vol. XIX, p. 368.

Fig. 107.—SALEMITE OUTCROP (IN THE FOREGROUND) AND LEDGE OF UMPTEKITE GABBRO (BEYOND THE PATH), SALEM NECK.

Fig. 108.—UMPTEKITE GABBRO CUT BY VEINS OF PULASKITE SYENITE, SALEM NECK.

limonite. The phenocrysts occur as crystals with a square cross-section, owing to the presence of the base and brachypinacoid; in addition to the two cleavages, there is a rough transverse fissuring. The crystals are quite glassy when fresh. The different feldspar sections show marked optical peculiarities; there is often a very fine single- or double-twinning (microcline); sometimes the whole of one section of the mineral consists of irregular areas not extinguishing in common, which resemble the phenomena produced by mechanical causes. These areas contain very fine lines crossing each other at various angles in the different areas; in other cases there is a very fine zonal structure. Sections prepared parallel to the base show this fine, irregular double-twinning, and give an extinction 1° to 2° oblique to the line of the second cleavage ($\infty \breve{P} \infty$); and sections parallel to the latter cleavage give an extinction about 9° oblique to the line of the first cleavage, with an obtuse positive bisectrix about perpendicular to the face, the acute bisectrix making an angle of 9° with the basal cleavage. These sections sometimes show a very fine, indistinct microperthite striation. The angle between the two cleavages was determined in the reflecting goniometer as approximately 89° 42′, about that of microcline. The specific gravity of fragments determined by Westphal balance and Thoulet solution was between 2.570 and 2.572.

The following analyses of the feldspar (I.) and the rock (II.) were made in the laboratory of the United States Geological Survey at Washington by Dr. Thomas Chatard.

	I. Feldspar.	II. Keratophyre.
H_2O at 110° C.	.04	.91
H_2O at red heat	.37	1.28
SiO_2	65.66	70.23
TiO_2[1]	...	.03 ?
P_2O_5	...	.06
Al_2O_3	20.05	15.00
Fe_2O_3	traces	1.99
FeO	traces	
MnO	.13	.24
CaO	.67	.33
MgO	.18	.38
K_2O	6.98	4.99
Na_2O	6.56	4.98

[1] The TiO_2 was not very pure, and its presence is not absolutely certain.

	III. Gmelin, No. 1.	IV. Gmelin, No. 2.
SiO_2	65.90	65.19
Al_2O_3	19.46	19.99
Fe_2O_3	.44	.63
CaO	.28	.48
MgO		
K_2O	6.55	7.03
Na_2O	6.14	7.08
H_2O	.12	.34

Specific gravity, 2.587.

It is evident from the analyses and optical properties that this is a triclinic soda-potash feldspar of remarkable purity, with very evenly balanced percentages of Na and K, belonging to the anorthoclase group of Rosenbusch. For comparison, are appended analyses (III. and IV.) by Gmelin, of anorthoclase from the augite syenite of Norway (Brögger, "Die Sil. Etagen 2 und 3," etc., p. 261). In the rock as a whole, the same even balance between Na and K is noticeable, and the insignificant quantity of lime and magnesia. Allowing for the free quartz, base and decomposition products as causing a relative increase of silica and iron and decrease of the alumina and alkalies, it is evident that the feldspars of the ground-mass are closely allied chemically to the porphyritic crystals, and are probably also anorthoclase. The rock is therefore a very pure type of keratophyre.

The microscopical structure of the sections made is as follows:

No. 1. Keratophyre with anorthoclase crystal cut obliquely to an optic axis. Ground-mass made up of minute twinned lathshaped crystals of feldspar, somewhat kaolinized, some quartz, and an earthy fibrous kaolinized base. In the center of the porphyritic feldspar crystal are numerous microliths and a few ferritic masses, similar to and probably composed of the base, which penetrates the edges of the crystal.

No. 2. Keratophyre and an aggregate of the porphyritic crystals. Ground-mass nearly as in No. 1. One of the phenocrysts shows twinning after the Carlsbad type.

No. 3. Keratophyre with one porphyritically inclosed crystal (see Fig. 113). The crystal is cut nearly parallel to the second cleavage, and gives an almost perfect interference figure of the positive bisectrix. The basal cleavage is well developed, and the striæ, or fine twinning, are well marked in polarized light. The ground-mass is more generally composed of the minute lath-shaped feldspar crystals, some of which are clearly twinned anorthoclase of the same form as the larger crystals. There are also small patches of quartz.

No. 4. Keratophyre with one large porphyritic feldspar crystal cut obliquely to

Fig. 109.—PHOTOMICROGRAPH OF HORNBLENDE UMPTEKITE GABBRO FROM SALEM NECK.

Fig. 110.—PHOTOMICROGRAPH OF UMPTEKITE GABBRO FROM EASTERN SIDE OF MISERY ISLAND.

the brachydiagonal (see Fig. 114), which in polarized light shows a microperthitic intergrowth and a very perfect example of fine and interrupted twinning. Through the crystal are several fluid cavities and a few microliths of a reddish color. The ground-mass is more kaolinized, and the minute lath-shaped crystals are less distinct. Small, irregular masses of quartz and considerable limonite and earthy matter pervade this section.

No. 5. Keratophyre section cut across a joint plane which is filled with vein quartz : numerous irregular patches of quartz are scattered all through the section. One mass is a basal section of original (?) quartz; it gives the uniaxial cross, and is shown to be positive by the mica plate. Some scales of biotite and numerous small grains of magnetite are seen in the ground-mass, which is composed of a fibrous, feebly polarizing kaolinized mass of the decomposed minute lath-shaped feldspar crystals. One of the inclosed phenocrysts cut nearly parallel to the base shows numerous microlithic inclusions, and several fluid cavities in which the bubble movement is seen. The outer edge is deeply penetrated by the ground-mass.

The occurrence of this keratophyre as a surface flow, in close proximity to the large intrusive masses of nepheline syenite, pulaskite syenite and Essexite of Salem Neck and the islands in Salem harbor, and the augite syenite of Marblehead and the Beverly shore, is interesting, as showing the various forms assumed here by the alkaline magmas under different geological conditions or at different periods.

CHAPTER VIII

IGNEOUS VOLCANIC ROCKS

These rocks are easily separated into two great groups, the acid and the basic volcanics. The acid volcanics occur in massive forms. Exposures may be seen on Marblehead Neck, at Swampscott, Lynn, and Saugus, and from there extending into Middlesex County. (See Figs. 115, 116.) These rocks also extend easterly into the bay by islands and ledges. Another area appears at Rowley and Newbury in the form of a long and comparatively narrow mass not over one mile in width, extending in a northeasterly direction from Batchelder's brook, at Clay lane, Rowley, across Rowley and Newbury to the tidal marsh beyond Pine island.

The acid volcanics are tufaceous, fragmental, and massive, and the exposures are more extended in area than the basic volcanics. The massive effusives often possess a compact cryptocrystalline felsitic texture, and on weathered surfaces are seen as banded structures with light and red to gray tints which conspicuously reveal curving and crumpled lines of flow movement. This fluxion banding, if the rock is much weathered, is accompanied by an easy cleavage into slabs parallel to the fluxion planes. A good example may be observed at Boden's point, Marblehead Neck. Below high-water mark, in the harbor off Boden's point, occurs a coarse breccia or aporhyolite tuff, which is covered by a sheet of lava rock, keratophyre, composed of anorthoclase feldspars. The keratophyre at this point is only exposed below high-water mark. It also appears on a ledge east of the Eastern Yacht Club's pier. On Marblehead rock, weathered surfaces of these banded forms of volcanic rocks are conspicuously seen. (See Fig. 112.) Amygdaloidal types of the basic volcanics occur in Rowley on the northern side of Clay lane, near the Dummer Academy grounds, and may be traced for nearly two hundred yards on the summit of the ridge. These amygdules are round, and of a red color merging into lighter shades. In cross section, they are seen to be composed of a fine radiating structure with an open center. In some instances the centers are much lighter in color. A partial analysis by Mrs. E. H. Richards, of the Massachusetts Institute of Technology, shows a composition of about one half

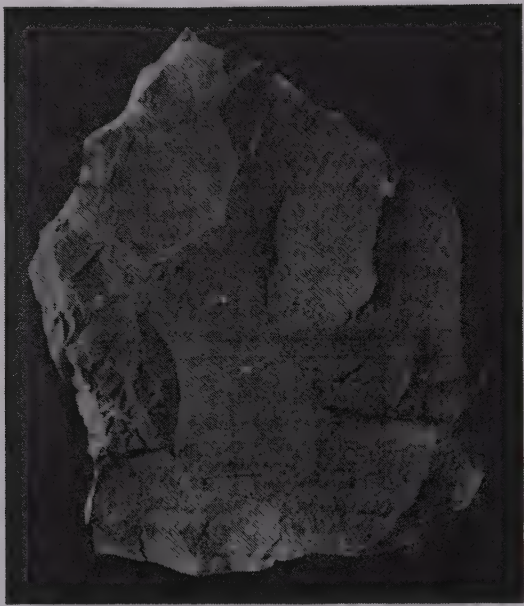


Fig. 111.—KERATOPHYRE FROM THE HARBOR SIDE OF MARBLEHEAD NECK.
Anorthoclase crystals appear as white spots. Size of block 6 x 10 inches.

112.—FOLIATED APORHYOLITE FROM A BARE LEDGE OFF MARBLEHEAD NECK, SHOWING WEATHERED SURFACE.

silica. They are forms of spherulites and vary in size from a small pea to a half inch in diameter.

At Kent's island, Newbury, these rocks are found in great variety. One large mass occupies the greater part of the center of the island and is so much decomposed that it is nearly kaolin. An area on the west side of the island has a deposit which is fine and white as chalk and is an excellent pottery clay.

Fluxion-banded basic forms are found on Eagle hill, Kent's island. The rock is vesicular on the bank of Parker river and at the extreme eastern part of the island, but it is epidotic on the summit of the hill. Previous to the intrusion of these volcanics, the original bed-rocks of the island were slates and sandstones cut by a mass of quartz hornblende diorite which is now cut and brecciated by the aporhyolites, while the sedimentary beds are calcined and so greatly metamorphosed that in places they are hardly recognizable. At the contact of the volcanics and the diorite mass, on the southern part of the island, the rocks are well mineralized with zinc, copper, iron, and galena. During the mining excitement in 1875, a shaft was sunk at this point. On the southeastern part of the island, by the side of the railroad track, there is an exposure of a conglomerate in which nearly all of the fragments are angular, and not only comprise volcanics but also fragments of diorite and sandstone. Thin sections of the volcanics from Pine island, Newbury, show trichites in a glassy ground-mass. South of Parker river, in Rowley, is a spherulite rock commonly called toadstone. It is a volcanic form in a long tongue or dike extending from the mass north of the river and here cutting the diorite which is in turn cut by an olivin basalt dike. This dike has calcined the spherulitic rock so that the spherulites are of a reddish color merging into black and giving a distinct form to the rock near its contact with the dike.

At Marblehead Neck and on High rock, Lynn, narrow dikes of quartz porphyry, a later formation of the volcanic series, cut through all the other numbers of these rocks, showing them to belong to a later period. A fine example may be seen at the first outcrop on approaching Marblehead Neck, and another exposure, cutting across the Neck to the ocean, appears by the side of the lane which leads from Tucker's landing to the Main street on the Neck. South of the lighthouse this rock is extremely hard. It has the characteristic conchoidal fracture with a very perfect jointing, and is found in blocks two or three inches wide and equally thick and suggesting, in appearance, tiles in regular layers. Cat island and Lowell island are largely agglomerate with several distinct forms, both coarse and

fine, and green and darker colored. Satan rock is a brick-red spherulitic aporhyolite with a glassy base. The Gooseberry islands are a conglomerate aporhyolite, and Halfway rock is a mass of coarse porphyritic aporhyolite containing numerous lithophase forms. These delicate shell-like structures are identical in form with those taken from the obsidian cliffs in the Yellowstone and figured in the Seventh Annual Report of the United States Geological Survey, pages 264–265.

A quartz porphyry volcanic dike at Marblehead which cuts hornblende diorite, has numerous fine examples of quartz phenocrysts surrounded with spherulites. This rock is a liparite. (See Fig. 117.) East of Boden's point, on the harbor side, the banded-fluxion rock (see Figs. 118, 119, 120), is succeeded by a massive porphyritic form of the basic series which contains veins of epidote. This is joined to a coarse breccia, the bed upon which the flow of keratophyre rests. Northeast of Sparhawk beach, the high bluff is composed of a purplish feldspar porphyritic aporhyolite which assumes a fluid structure near the Point and contains numerous concretionary formations, varying in size from a small pea to a diameter of two feet. (See Fig. 121.) Some are flattened as if after having been ejected into the air they had fallen back into the viscid lava.

The primary constituents which have been preserved in these volcanics are the alkali feldspars, quartz, and magnetite. Lime-magnesian and ferro-magnesian minerals are only found at or near a contact with some basic dike or in the agglomerate series. On Lowell island, glaucophane is usually present. Feldspars occur both as scattered phenocrysts and as components of the ground-mass, assuming granular forms in lath-shaped crystals, and radiating fibers. The lath-shaped feldspars are usually microperthitic. The extinction indicates that albite, orthoclase, and anorthoclase are present. Quartz occurs in the form of phenocrysts and also as a constituent of the ground-mass. The textures found in these lavas are the granular trachytic porphyritic fluxion, spherulitic, perlitic, and amygdaloidal.

By megascopic examination, hand specimens exhibit as great a range of color as of texture. Light-green to dark grass-green shades occur and gray with various shades of pink and purple and also a brick-red. The fragmental materials, such as the breccias and agglomerates, are readily recognized by the weathered surfaces, which owe their character to the variously colored fragments contained in a light-green or pink base. Red hematite is disseminated through the feldspathic mineral as a microscopic dust and produces the various shades of red and pink. The green colors

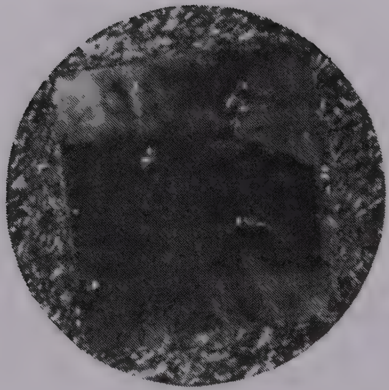


Fig. 113.—PHOTOMICROGRAPH OF AN ANORTHOCLASE CRYSTAL IN KERATOPHYRE FROM MARBLEHEAD NECK.

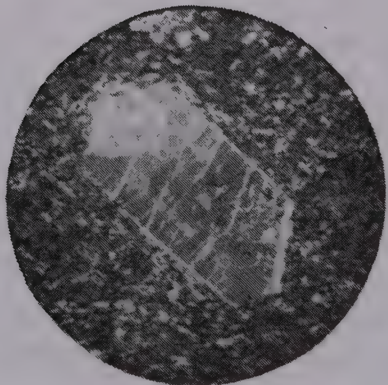


Fig. 114.—PHOTOMICROGRAPH OF AN ANORTHOCLASE CRYSTAL IN KERATOPHYRE FROM MARBLEHEAD NECK.

are due to pyrite and epidote, derived from the alteration of the feldspathic ground-mass.

In this area, the age of these volcanics is somewhat problematical. As veins and masses are erupted into the Cambrian sedimentary rocks at Saugus and Lynn, and especially at Kent's island, undoubtedly they are Post-Cambrian. They are also younger than the hornblende granite, for on Marblehead Neck they cut through and inclose masses of these granites which are younger than the diorites. Hornblende diorite is cut by a spherulitic aporhyolite liparite dike at Throgmorton's cove, Marblehead.

The agglomerates on Lowell island and Cat island are rhyolitic tufas, the microscopical structure showing them to be composed of sharp-edged fragments of the aporhyolites and volcanic glass embedded in a ground-mass of ashy materials. Much of the glass has been altered to quartz and the ash to an earthy chloritic mass. Some magnetite appears and also spherulites and skeleton-crystals of augite. In places the fluxion of the micro-felsitic ground-mass shows secondary quartz in radiating fibrous lines.

North Gooseberry island is a large mass of porphyritic aporhyolite containing considerable amounts of original glass, and a conglomerate aporhyolite in which the pebbles are weathered out very conspicuously. (See Fig. 122.) Some of the well-rounded pebbles are from one to three inches in diameter. The fine-grained flow has a perlitic structure and contains much original glass, in twisted and curved forms.

At the northeastern end of Thatcher's island there is a wide, dike-like mass occupying at least a third of the area of the island, which seems to be a spherulitic quartz porphyry. A microscopical examination of thin sections of this rock shows it to be composed of quartz phenocrysts, with phenocrysts of orthoclase perthite, having albite intergrowths across the crystals. Glaucophane, biotite, and magnetite are present; also a felsitic ground-mass in which is considerable quartz containing original glass and numerous fluid cavities. In the ground-mass are rutile crystals with prisms joined at right angles with each other. Macroscopically this dike resembles the paisanite at Magnolia,[1] and in the cove between Woodbury's point and Hospital point, Beverly.

[1] Journal of Geology, Vol. VII, pp. 111–113.

CHAPTER IX

THE MINERALS OF ESSEX COUNTY

THE following list of the minerals of Essex County has been prepared after a careful examination of the work of the earlier mineralogists, and diligent search in almost every portion of the County for species not previously noticed. Doubtless it is not absolutely complete. In studying the rock formations, more than sixteen hundred thin sections have been made for microscopical study. Of the minerals enumerated nearly all are represented by excellent specimens in the County collection in the museum of the Peabody Academy of Science at Salem. In connection with the minerals will be found collections illustrating the rocks of the County and the geological formations, including photographs of the more interesting features. The rocks from which these minerals were taken represent twenty-nine distinct rock-formations, and several thousand outcropping ledges, the greater number of which have never been broken into except to collect the few specimens required to determine the character of the rock. As these ledges are worked into and studied they will, without doubt, furnish many mineral species new to the County, and an extremely interesting field is open to the mineralogist. The arrangement of the minerals in this list follows the text book of Prof. E. S. Dana, the tenth revised edition.

GOLD. The gray copper, galena, and quartz, from the Chipman silver mine at Newbury, contain gold, and gold has been reported from various other mines in the neighborhood, and also from Boxford, Topsfield, Lynnfield Centre, and Saugus. The analysis of the gray copper from the Chipman mine made by Prof. R. H. Richards of the Massachusetts Institute of Technology,[1] gives: silver, $1,422.00 per ton; gold, $145.12 per ton and 27 per cent of copper. The galena (30 pounds) from the Chipman mine analyzed by Professor Richards, yielded 25 lbs. of refined lead, 436.32 grains of silver and 4.19 grains of gold. An analysis of this galena made by the author at the Lawrence Scientific School gave silver at the rate of 27 ounces per ton. The gray copper of the quality above indicated is very

[1] Proceedings, Boston Society of Natural History, Vol. XVII, pp. 200–204.

Fig. 115.—CASTLE HILL, SAUGUS, A MASSIVE OUTCROP OF APORHYOLITE.
An ancient volcanic rock.

Fig. 116.—CASTLE HILL, SAUGUS.

rare even in Newbury, and it is doubtful if it is to be found in the County in sufficient quantities to be mined at a profit.

GRAPHITE. This occurs in minute foliated scales in the granitic rocks of Peabody and Danvers, and in the slaty, carboniferous shales of Topsfield, Middleton, and Lynnfield Centre.

STIBNITE: Gray Antimony. Found associated with galena at the Newbury and Newburyport silver mines.

MOLYBDENITE. Found in foliated masses of considerable size at the Pomeroy granite quarry at Gloucester, in the augite syenite at Salem Neck, and some good specimens have been found in the diorite at Marblehead.

SILVER ORE. At Newbury, Newburyport, Amesbury, Rowley, Boxford, and Lynnfield Centre.

GALENA: Lead Ore. Found in the places last named.

BORNITE: Variegated Copper Ore. At the Luther Noyes copper mine and the southern part of Kent's island, Newbury.

CHALCOPYRITES: Copper Pyrites. Found at the Luther Noyes copper mine, the Chipman silver mine, and at Kent's island, Newbury, the Stephen Osgood mine in South Georgetown, and the old Governor Endicott copper mine in Topsfield.

SPHALERITE: Zinc Blende. This occurs in considerable masses at all of the mines in Newbury, Newburyport, and Rowley and also in much larger quantities in the John Pettingill mine at Amesbury.

PYRRHOTITE: Nickel Ore. From the Luther Noyes nickel mine in Newbury, and in a small vein exposed in the augite syenite at Poorhouse hill in Beverly.

PYRITE: Iron Pyrites. This occurs in large masses near the Harriman mine at Boxford, and in Newbury in connection with the galena and silver ores. It is also common in small quantities in nearly all of the bed-rocks of the County.

MARCASITE: White Iron Pyrites. Found in large masses at the Luther Noyes nickel mine, Newbury.

ARSENOPYRITE: Mispickle. This occurs in thin sheets or veins at the John Pettingill mine, Amesbury, and good specimens were found at an old mine near the Parker river, Rowley.

TETRAHEDRITE: Gray Copper. Good specimens of this mineral were found in the dump heaps of the Chipman silver mine, Newbury, and at the Stephen Osgood mine, South Georgetown.

HALITE: Salt. Found as incrustations and in acicular crystals on rocks and the borders of tide pools at the sea-shore.

FLUORITE: Fluor-spar. In irregular, crystalline masses in the granitite at the quarry of the Rockport Granite Co., Rockport, and also associated with galena at Lynnfield Centre.

HEMATITE: Specular Iron. Found on the surfaces of the slickensides of diorite at Salem, in amphibolite at Putnamville, and in hornblende granites at Peabody.

HEMATITE, var. Micaceous Hematite. Found in the bed-rock of the Tophet hill lost gold mine, Lynnfield Centre.

HEMATITE, var. Red Ochre. At Beverly Cove, Danvers, Topsfield, etc. This is the common anhydrous form.

MENACCANITE: Ilmenite: Titanic Iron. Seen in microscopic patches in nearly all of the eruptive rocks, especially in the augite syenites, diorites, and mica-schists.

LEUCOXENE. This mineral, a decomposition product of the titanite, is usually seen surrounding the titanite or entirely replacing it.

MAGNETITE: Iron. This occurs in masses in the elæolite zircon syenite at Great Haste ledge, Salem harbor, and is common in crystals and small grains in all of the eruptive rocks of the County.

CHROMITE: Chromic Iron. In octahedral crystals in the limestone and serpentine at the Devil's basin, Newbury.

RUTILE. Common in microscopic crystals in the metamorphic Cambrian rocks in all parts of the County. Larger crystals occur in the granites at Swampscott, West Wenham, etc.

TURGITE: Red Ochre. An earthy form of this mineral occurs in a hillside, northwest of the old meeting-house, at Beverly Farms.

LIMONITE: Brown Hematite: Bog Iron Ore. Found in the beds of brooks and small ponds in nearly all of the towns in Essex County. This was the ore used at the Saugus Iron Works, in 1643, the first iron-casting works in America.

LIMONITE: Brown Ochre. At the mineral paint mine, Georgetown.

LIMONITE: Yellow Ochre. At Danvers, Topsfield, Newbury, etc.

LIMONITE: Clay Iron Stone. Good specimens of this mineral are found in pockets in the granite at the Pomeroy quarry, Gloucester.

XANTHOSIDERITE. Found in segregated masses, stalactitic and botryoidal in form, in crevices of the granite at the quarry of the Rockport Granite Co., Rockport.

BRUCITE. A mineral belonging to the magnesia group, found associated with serpentine at the serpentine ledge, Lynnfield Centre.

WAD: Bog Manganese. Found in large masses in a meadow and brook

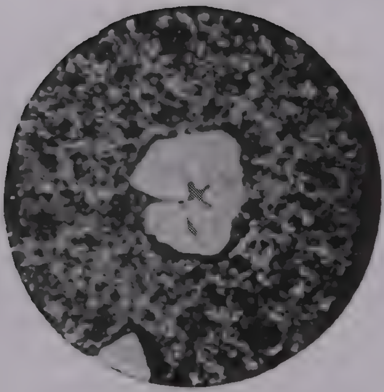


Fig. 117. — PHOTOMICROGRAPH OF LIPARITE.
A quartz porphyry aporhyolite with spherulites.

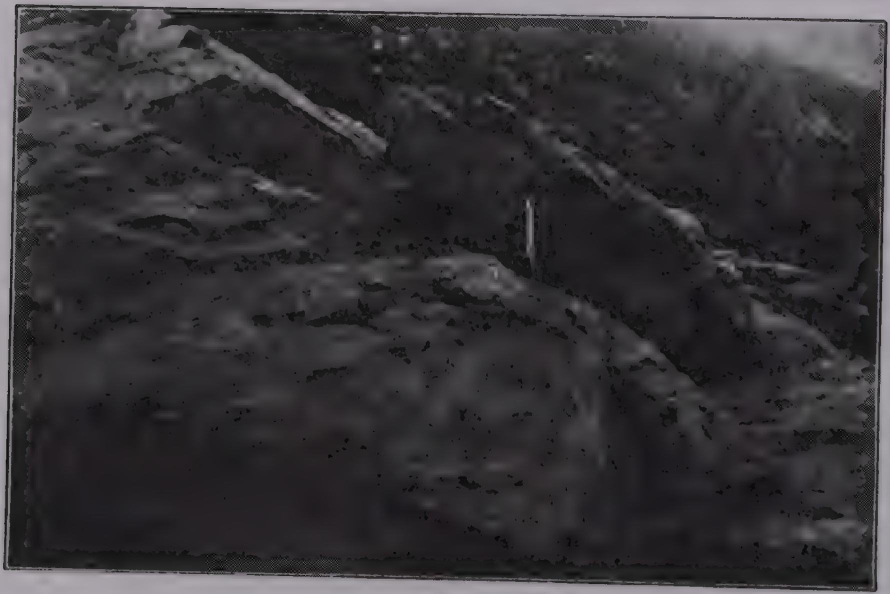


Fig. 118. — APORHYOLITE OUTCROP ON THE HARBOR SIDE OF MARBLEHEAD NECK, SHOWING THE FLOW OF THE LAVA.

at Putnamville, and in the form of rounded concretions in small ponds and spring-holes at Peabody and Topsfield.

QUARTZ. Massive vein quartz occurs at North Beverly, Danvers, and various other places in the County.

QUARTZ: Rock Crystal. Found in large masses and crystals in pegmatite veins at Andover, Nahant, Rockport, etc.,

QUARTZ: Drusy Quartz. In minute crystals at Danvers, Nahant, and West Newbury.

QUARTZ: False Topaz. Light Yellow color, Rockport.

QUARTZ: Smoky Quartz. The massive vein form is found in the rhyolites of Marblehead and in the granite of Gloucester and Rockport.

QUARTZ: Cairngorm Stone. Found in nearly black crystals at the Pomeroy quarry, Gloucester, and at Rockport.

QUARTZ: Milky Quartz. Massive veins occur at South Georgetown and Groveland.

QUARTZ: Ferruginous Quartz. In the carboniferous slates of Topsfield.

QUARTZ: Rose Quartz. Occasionally found in the glacial drift.

PRASE: Actinolitic Quartz. A vein occurs at Bass Point, Nahant.

CHALCEDONY. Good specimens occur at Prospect Hill, Beverly, and it is also found filling the amygdules of the amygdaloidal melaphyre at Saugus.

BASANITE: Chert. Found in the Cambrian rocks at Peabody, Middleton, Rowley, and Nahant head, Nahant.

JASPELITE. At Saugus Centre and Nahant. This is the so-called red jasper as popularly known.

QUARTZITE. At Saugus, Lynnfield Centre, etc., forming large beds in the lower Cambrian rock-mass.

OPAL, var. Silicious Sinter. Found as segregated, granular, stalactitic masses at the contact of the augite syenite and granite in Beverly.

OPAL, var. Tripolite: Infusorial Earth. Found in beds of brooks and meadows in Danvers. At West Boxford, beds occur two feet or more in thickness.

HYPERSTHENE. In irregular, cleavable, crystalline grains and masses in the hypersthene gabbro at Misery island and Salem Neck.

WOLLASTONITE: Tabular Spar. A bladed variety of this mineral is found at the Devil's den, Newbury.

DIALLAGE. Found in large crystalline masses at the Luther Noyes nickel mine, Newbury.

PYROXENE, var. Augite. In irregular crystals in the augite nepheline syenite at Salem Neck, Beverly, and Manchester.

Diopside, var. Brown Augite. This occurs as irregular, microscopic crystals in the augite nepheline syenite on the Pickman estate, Beverly Cove.

Acmite. This occurs as small acicular crystals in the augite syenite at Powder House hill in Essex, and at Lanesville in Gloucester.

Ægirine. Typical bent crystals, sometimes three inches long, are found in the ægirine syenite at Gale's point, Manchester. It is also seen in thin sections of the elæolite zircon syenite of Salem Neck and Beverly, when studied with the microscope.

Enstatite. In micro-crystals in the olivin gabbro of Salem Neck.

Bronzite. Found with the enstatite on Salem Neck, and also in a coarse pegmatitic mass on Misery island, Salem Harbor.

Hornblende. Irregular crystals are abundant in the hornblende granite of Peabody and, microscopically, it is common in the diorite, syenites, and the dike rocks.

Tremolite. At the Devil's basin, Newbury.

Actinolite. Long crystals are found at Bass Point, Nahant, and it is also found in a large pegmatite boss in the quarry of the Rockport Granite Co., Rockport.

Asbestus, pseudomorph of Actinolite. A vein six inches wide, in the diabasic norite, occurs at Bass Point, Nahant.

Arfvedsonite: Alkali Hornblende. Irregular crystals are found at Salem Neck, and larger masses in the elæolite zircon syenite on Coney island, Salem harbor.

Ainigmatite. Rare, but found in microscopic masses in the elæolite zircon syenite, Great Haste ledge, Salem harbor.

Cossyrite. In microscopic crystals in the augite syenite at Magnolia.

Glaucophane. A deep blue hornblende. In massive forms in the augite hornblende granite at Pickering's point, Salem, and in the granite porphyrite at Marblehead Neck, etc.

Chrysolite: Olivin. Found in porphyritic crystals in olivin basalt dike rocks, Salem Neck, etc.

Fayalite. A large mass, at a depth of sixty feet, occurs in the quarry of the Rockport Granite Co., Rockport.

Danalite. In irregular masses and microscopic blebs scattered through the hornblende biotite granite at the quarry of the Rockport Granite Co., Rockport, and also at the Pomeroy quarry, Gloucester.

Garnet. Garnet occurs plentifully in a garnet schist outcrop between Powder House hill and White's hill in Essex, and elsewhere in the County.

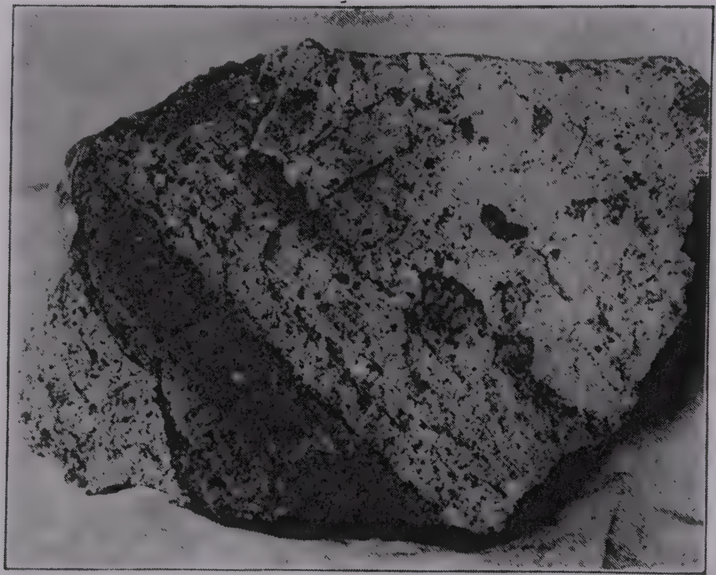


Fig. 119.—APORHYOLITE, SHOWING WEATHERED SURFACE.
High Rock, Marblehead Neck.

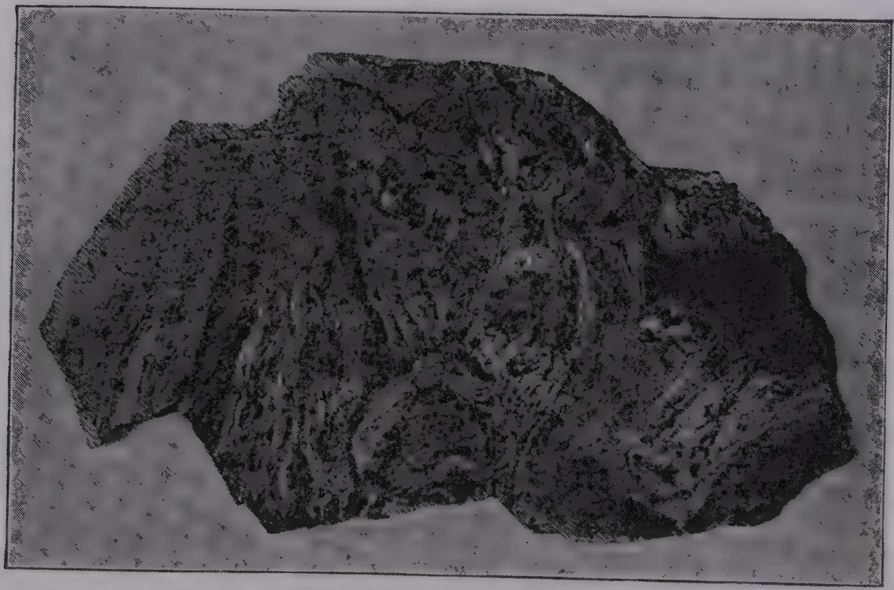


Fig. 120.—BANDED APORHYOLITE, SHOWING THE FLOW OF THE MAGMA PREVIOUS TO ITS CONSOLIDATION. SIZE OF SPECIMEN, 14 x 20 INCHES.
Bowden's Point, Marblehead Neck.

ALMANDITE GARNET. Abundant in the biotite muscovite granite at Andover.

GROSSULARITE GARNET: Cinnamon Stone. In a drift boulder at Nahant.

ZIRCON. Crystals with double terminations are abundant in the elæolite zircon syenite at Salem Neck, Beverly, etc.

VESUVIANITE. Specimens from a vein in the serpentine at the Devil's basin, Newbury, were analyzed by Prof. W. O. Crosby, and determined as vesuvianite.

EPIDOTE. Veins with fine drusy crystals are found at Egg rock, near Nahant; in the diabase at East point, Nahant; and also in the rhyolites at Marblehead, Clifton, etc.

ALLANITE. Radiated crystals are found in the diorite at Beverly, and long slender crystals are found in the augite syenite at Beverly and West Gloucester and in the granite at Swampscott. The specimen determined as orthite and described in the "American Journal of Science and Arts," Vol. XXXIII, page 198, should undoubtedly be referred to Allanite.

ORTHITE. Found in radiated crystals in the hornblende biotite granitite at the quarry of the Rockport Granite Co., Rockport.

ZOISITE. This occurs in fine blue crystalline masses in the zoisite gneiss and the hornblende epidote gneiss at Andover, Georgetown, and Newbury.

IOLITE. Found in corderite gneiss at Marble Ridge, North Andover.

PHLOGOPITE MICA. In granitite at Rockport.

BIOTITE MICA. In augite syenite at Salem Neck and Beverly, and also in granitite at Rockport.

LEPEDOMELANE. Found in hexagonal plates of a bronze color in the Pomeroy quarry, Gloucester.

ASTROPHYLLITE. In the quarry of the Rockport Granite Co., Rockport.

MUSCOVITE MICA. Common in the biotite muscovite granite at Andover, Methuen, and Rowley.

LEPIDOLITE: Lithia Mica. In mica-schist at Ballardvale, Andover, Ward's Hill, Bradford, and Methuen.

SERICITE. This occurs in irregularly banded plates in the jaspelite at Saugus Centre, etc.

SCAPOLITE: Wernerite. In 1890, microscopic grains of scapolite were discovered in thin sections of the hornblende granite collected at a quarry

on Humphrey street, Swampscott, which is believed to be the only record of this mineral having been found in granite.

CRYOPHYLLITE. In the hornblende biotite granitite at Rockport.[1]

ANNITE. Found in the hornblende granite at Rockport.[2]

[1] Chemical analyses of three sections of cryophyllite from Rockport, made by R. B. Riggs, of the United States Geological Survey, gave the following results.

A. Brilliant, broadly foliated, blackish-green variety.
B. Paler, dull green, less lustrous, probably somewhat altered.
C. Granular, resembling chlorite, minute six-sided prisms, color dark green.

	A	B	C
SiO_2	51.96	51.46	52.17
Al_2O_3	16.89	16.22	16.39
Fe_2O_3	2.63	2.21	4.11
FeO	6.35	7.66	6.08
MnO	.24	.06	.32
CaO	.12	traces	traces
MgO	.03	.17	traces
Li_2O	4.93	4.83	5.03
Na_2O	.92	.95	.60
K_2O	10.66	10.65	10.54
H_2O	1.26	1.06	1.43
F	6.78	7.44	7.02
	102.77	102.71	103.69
Less oxygen—O equivalent to F	2.86	3.11	2.95
	99.91	99.60	100.74

[2] A chemical analysis of the annite from Rockport, made by R. B. Riggs of the United States Geological Survey, gave the following result:

SiO_2	32.03
TiO_2	3.42
Al_2O_3	11.92
Fe_2O_3	8.00
FeO	30.41
MnO	.21
CaO	.23
MgO	.06
NiOCoO	
Li_2O	traces
Na_2O	1.54
K_2O	8.46
H_2O at 105° / H_2O above 105°	4.19
	100.47

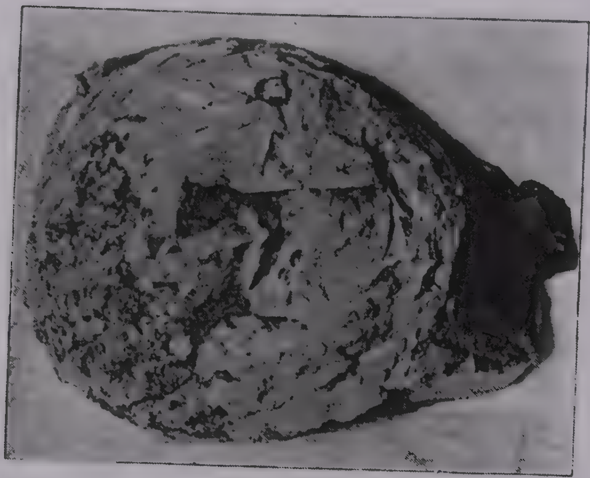


Fig. 121.—APORHYOLITE CONCRETION, 9 INCHES IN DIAMETER.
Marblehead Neck.

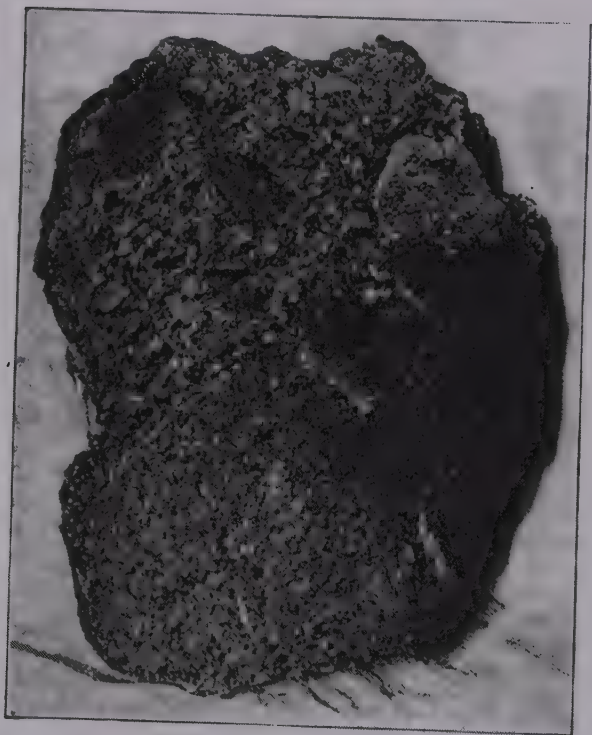


Fig. 122.—APORHYOLITE CONGLOMERATE, 12 x 14 INCHES IN SIZE.
South Gooseberry Island, Salem Harbor.

ELÆOLITE. This occurs in large irregular crystalline masses in the elæolite zircon syenite at Beverly, Salem Neck, etc.

NEPHELITE: Nepheline. Found in small micro-crystals in the augite nepheline syenite at Salem Neck, Beverly, and Gloucester.

CANCRINITE. This occurs in minute irregular masses in the elæolite zircon syenite at Salem Neck where it is lemon yellow in color. It is more abundant at Great Haste ledge and the Ram islands, Salem harbor, where the color is grayish to brown.

SODALITE. In coarse pegmatitic masses in the elæolite zircon syenite at Salem Neck, Great Haste ledge, and Beverly shore.

HYDRONEPHELITE. In radiated crystals in the elæolite zircon syenite at Salem Neck.

ANORTHITE. A large mass of this feldspar occurs at East point, Nahant, near the residence of Hon. H. C. Lodge.

LABRADORITE. This occurs in large crystals, some of which are three inches long by one and one half inches wide, in the gabbro at Bay View, Davis Neck, and Lanesville in Gloucester; also in porphyritic dike rocks in various localities.

ALBITE. Fine glassy, multiple-twinned crystals are found at the Pomeroy quarry, Gloucester.

ORTHOCLASE. Simple and twinned crystals are found in pegmatitic masses in the granite at Rockport. Common in the granite.

MICROCLINE: Amazon Stone. Specimens of a bright verdigris-green color are found at Briscoe hill, Beverly, and at Gloucester, and Rockport.

MICROCLINE MICROPERTHITE: Soda Microcline of Brögger. Found in coarse crystalline masses in the elæolite zircon syenite at Salem Neck.

ORTHOCLASE MICROPERTHITE: Albite and Orthoclase intergrowths. In the elæolite zircon syenite at Coney island, Salem harbor.

SANADIN. In crystals from the Bostonite porphyry (Rosenbusch), a dike rock on Coney island, Salem harbor.

ANORTHOCLASE. In crystals in the keratophyre at Marblehead harbor.[1]

PREHNITE. Rare; in reniform or globular masses in the hornblende gabbro at Nahant.

NATROLITE. This occurs as a secondary pseudomorph of elæolite on Salem Neck and in amygdules in the amygdaloidal melaphyre at Rowley.

STEATITE: Soapstone. In a massive bed associated with the serpentine at Newburyport.

[1] See Bull. M. C. Z., Geol. Sur., Vol. II, No. 9, p. 167.

Talc. The fine granular variety known as French chalk is found at Newburyport near the silver mines.

Serpentine: Noble Serpentine. Of a rich oil-green color at Devil's den, Newbury.

Serpentine: Common Massive Serpentine. At Devil's den, Newbury.

Serpentine: Foliated Serpentine: Marmolite. At Devil's den, Newbury.

Serpentine: Picrolite. At Devil's basin, Newbury.

Serpentine: Picrosmine. At Devil's basin, Newbury.

Serpentine: Baltimorite. At Devil's basin, Newbury.

Serpentine: Chrysotile: silky fibrous. At Devil's basin, Newbury.

Serpentine: Massive Serpentine, dark colored variety. At Lynnfield Centre.

Kaolinite. At Kent's island, Newbury, and at Little Niagara river, Bradford.

Tourmaline. Long acicular crystals, some of which in finely radiated groups and black in color, are found at South Groveland.

Andalusite. In veins of andalusite slate at Nahant, and near Flax pond, Lynn.

Andalusite: Chiastolite. Crystals are found in glacial drift at the Castle, Castle river, Ipswich.

Fibrolite. In the corderite gneiss at Marble Ridge, North Andover.

Titanite: Sphene. Micro-crystals are found in augite syenite at Salem Neck, Beverly, Magnolia, etc.

Bastite: Schiller Spar. Resulting from the alteration of pyroxine diallage in the diabasic norite, Nahant.

Pinite. Pseudomorph of orthoclase; at Eagle island, Little river, and Kent's island, in Newbury, etc.

Jeffersite. In broad crystalline plates resembling biotite mica; northwest side of Powder House hill, Beverly, and in the old lime-pits near Stevens' pond, Boxford.

Pennenite. In the Pomeroy quarry, Gloucester.

Delessite. This occurs as thin folia in seams of diorite at Salem, and in diabase dike rock at Bradford, etc.

Uralite. A paramorph of hornblende after pyroxene. This mineral is abundant, microscopically, in the quartz augite diorite of Newburyport, Carr's island, etc.

Fergusonite. Found in the granite at the quarry of the Rockport Granite Co., Rockport.

Fig. 123.—THE MINERALS OF ESSEX COUNTY, AS EXHIBITED AT THE PEABODY MUSEUM, SALEM.

Ruby Spinel. Rose colored specimens in massive form were found in the limestone at East point, Nahant, in 1905.

Apatite: Phosphate of Lime. Microscopic crystals occur abundantly in diorite augite syenite, and many dike rocks.

Apatite: var. Guano. Found incrusting the rocks at Great Haste ledge and Halfway rock, Salem harbor.

Calcite: Calc Spar. Often found in good rhombic crystals in the amphibolite gneiss at Putnamville.

Calcite: Dogtooth Spar. Near the Tri-Mountain House, Bass Point Nahant.

Calcite: Massive Granular Limestone. Found in large masses at the Devil's den and Devil's basin, Newbury, and at the old lime-pits in Boxford.

Calcite: Massive Blue Limestone. Interstratified with quartzite sandstone and slate in the carboniferous rocks at Topsfield.

Calcite: Statuary Marble. Specimens, pure white and fine grained, occur at the Devil's den, Newbury.

Calcite: Silicious Limestone. This belongs to the Olenellus Lower Cambrian period and occurs at Archelaus hill, West Newbury, at Rowley, and Nahant.

Dolomite: Magnesian Limestone. Found in veins in the serpentine at the Devil's den, Newbury.

Ankerite. Good rhombohedral crystals are found in the granite at the Pomeroy quarry, Gloucester.

Magnesite: Brown Spar. Found in the old serpentine ledge at Lynnfield Centre, and at Boxford and Newbury.

Siderite: Spathic Iron. Massive crystalline forms are found associated with the iron pyrites and galena at the Chipman mine, Newbury, and (rare) in small compound scalenohedrons and rhombic crystals incrusting the albite feldspars at the Pomeroy quarry, Gloucester.

Siderite, bronze var. In the Newbury mining region. The usual form is granular in structure.

Malachite: Green Carbonate of Copper. Found associated with gray copper at the Osgood mine, South Georgetown.

Azurite: Blue Carbonate of Copper. At the Osgood mine, South Georgetown.

Quartz. A quartz crystal, an inch broad, a pseudomorph of fluorite, deep scarlet in color, was found in the granite at the quarry of the Rockport Granite Co., Rockport.

Coal: Earthy Brown Coal. At the east side of Nahant, near the old iron mine.

Bog-butter: Oxygenated Hydrocarbon. Three feet below the surface, at Clifton, Marblehead.

Yttrocerite. On massive smoky quartz in the Rockport Granite Company's quarry, Rockport.

Fig. 124.—VIEW IN TOPSFIELD.
Looking across the geographical center of Essex County, showing the even sky-line and rounded outlines of the surface. The Ipswich river is seen in the center of the picture, and the drumlins, Hunslow hill and Prospect hill, are outlined at the left against the sky on the left.

CHAPTER X

THE QUATENARY PLEISTOCENE PERIOD: GLACIAL ICE EPOCH

The landscape of Essex County, and in fact of all New England, owes its generally rounded outline and level sky-line to the effect of an ice-sheet, or continental glacier, which covered this region in the ice epoch. (See Fig. 124.) The thickness of this ice-sheet is computed to have been at least 2,290 feet. The summit of Mount Desert island, on the coast of Maine, is glaciated with fine striæ, or scratches, at an elevation of 1,527 feet above mean sea-level. Prof. Louis Agassiz is quoted as saying, that no glacier could cross a ridge unless its thickness was at least one half of the height above the ridge, and by this rule it may be judged that the ice-sheet on the coast of Maine was 763 feet in thickness over the summit of Mount Desert. To this should be added the height of Mount Desert — 1,527 feet, giving a total thickness of the ice-sheet above mean low water on the coast of Maine of at least 2,290 feet. As there is no material difference between mean low water at Mount Desert, and at Essex County, it is fair to presume that the ice-sheet over the latter region was also at least 2,290 feet in thickness. Inland from the coast one hundred and twenty-five miles is Mount Greylock, the highest elevation in the state and 3,555 feet above mean low water (Appalachian Club). By following the rule laid down by Professor Agassiz, the thickness of the ice-sheet in the Mount Greylock region must have been 5,301 feet, indicating a gradual slope of sixteen feet to the mile from Mount Greylock to the coast of Essex County.

At the close of the Tertiary period and during the ushering in of the Quaternary or Pleistocene period, occurred the great uplift or elevation of the land surface amounting to several thousand feet in North America. Probably this uplift was from one hundred and eighty to two hundred feet in Essex County. It raised the bed of the sea to high land from one to two hundred miles out from our present coast for the distance reaching from Jeffery's shoal to beyond Cape Sable. This uplift caused the rivers and streams to cut down their valley beds, thus forming the deep fiord-like channels and hollows which now reach out into the sea. Another

result of this uplift of the land surface was to change the climate from temperate to boreal. This arctic climate caused a glacial ice-cap to form over the uplifted land surface. It expanded from a center of accumulation in the Canadian highlands, and moved towards the southeast from the northwest, which is the direction in which it is known to have passed over Essex County as recorded by direction of the grooved, scratched, and striated surfaces of the ledges over which it passed. In many places it planed down the surfaces and rounded the outlines of hills and ledges, nearly always leaving fine scratches and striæ on their surfaces, a lasting record of glacial action. Some times even the tools — the rocks with which these scratches and grooves were made — are found in the boulder-till. (See Fig. 126.)

Glacial erosion is shown on the surface of bed-rock by grooves and scratches, or striated lines, and also by prominences of bed-rock which have been rounded. (See Figs. 70, 127, 128.) On looking northward from the top of Red Shank hill, at South Georgetown, the land surface appears like a billowy sea. (See Fig. 129.) This area is covered by a thin coating of drift-sand and gravel, and the true nature of these mounds is not apparent until the sand and gravel covering is removed, when the rounded surfaces of the bed-rock appear. The name *Roches Moutonnées* or "sheep backs" has been applied to this formation. A series of these "sheep backs," covered with drift and growths of forest trees, occur near the village of Topsfield, and have received the local name of "sugar-loaf" hills. The bed-rock forming these elevations in Topsfield is arkose, a conglomerate granite. (See Fig. 130.)

In nearly all parts of the County, the surface of the diorite bed-rock, wherever it is exposed, is distinctly glaciated. A fine example of a glacial groove in a hornblende diorite ledge may be seen beside the carriage road in Ledge Hill park, Salem. (See Fig. 128.) In the bottom of the groove are long, deep scratches and fine striæ, and beside the groove and on its western side, the whole surface of the ledge is glaciated with short and long grooves, deep scratches, striæ, and chatter-marks.

Similar glaciated surfaces of bed-rock may be seen in North Salem. In Danvers, nearly all of the diorite bed-rock shows glacial scratches. The direction of glacial ice-movement across this region is thereby recorded as having been from the northwest to the southeast. The granite and syenite bed-rocks also show glaciation, but the scratches and striæ have usually been removed by disintegration, leaving only the rounded surfaces to record the work of the glacial ice.

Fig. 125.—QUARRY OF THE ROCKPORT GRANITE COMPANY AT ROCKPORT.
Showing the general structure of the hornblende granite rock.

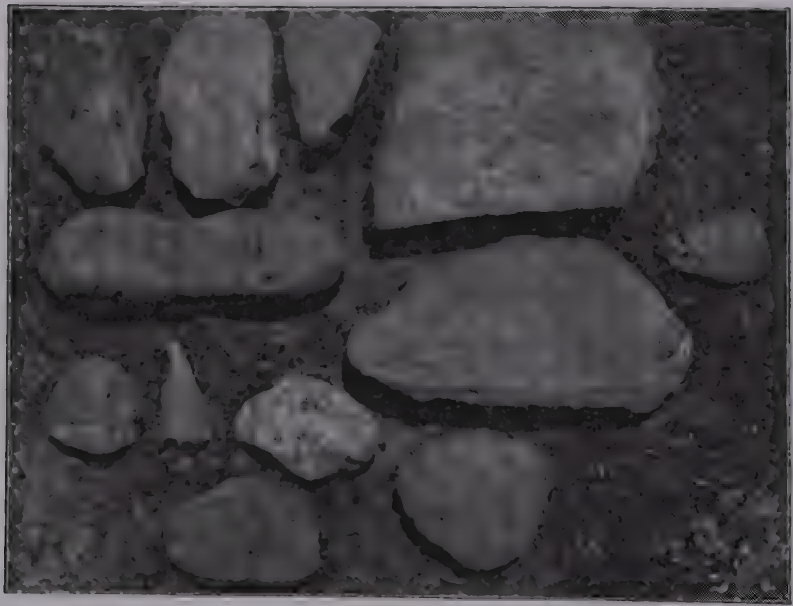


Fig. 126.—GLACIATED STONES FOUND IN BOULDER-TILL AT NORTH ANDOVER.
These stones probably were some of the tools which cut the glacial grooves, striæ, scratches, and chattermarks found on the surface of outcropping ledges.

Fig. 127.—GLACIATED DIABASE DIKE ROCK NEAR FLYING POINT, MARBLEHEAD NECK.

Fig. 128.—REMARKABLE GLACIAL GROOVE, 30 FEET LONG, 3 FEET WIDE, AND 5 1-2 INCHES DEEP, ON THE SURFACE OF A HORNBLENDE DIORITE LEDGE IN LEDGE HILL PARK, SALEM.

The topography of Essex County therefore owes its characteristic features to the work of the continental glacier. This glacial drift assumes within comparatively limited areas, forms so numerous and so varied as to render the region an exceptional one for study. The bare, rounded surfaces of the granite and other outcropping bed-rocks tell the story of a grinding force. The long sloping hills, the drumlins of boulder-till, the "kettle-holes" or sites where icebergs in front of a retreating ice-sheet had been buried in over-wash sands and gravels, are all to be seen in various parts of the County. Ridges, terraces, and cone-like masses of sand and gravel rising from a gently sloping incline of sand and clay, and leading to a pond or filled pond, now a peat swamp, alike mark the contact of an ice-block that was stranded at the present location of the pond or swamp. Moraines or circular ridges of gravel, and boulder trains or lateral moraines sometimes occupying drainage creases in front of the retreating ice-sheet, are among the forms assumed by the glacial drift. Another form is the long serpentine ridge or esker which records the presence of a drainage stream flowing under the ice-cap and grading its channel with sand and coarse gravel. Upon emerging from under the ice these streams deposited their loads of sand, gravel, and clay in the order of their coarseness, now to be seen in the form of bouldery gravel-banks, sand-plains, and clay-beds.

The ideal section of an ice-contact, with alluvium filling against the front of the ice edge of a glacier, will very well represent the formation of the kame topography on the south side of Forest river, west from the electric car sheds, in Marblehead. (See Figs, 131, 132.) These ice-berg holes are locally known as "the dungeons." They were formed by detached bergs of ice which became buried in the outwash gravel. When the ice melted, the covering of gravel fell in, leaving the place which had been occupied by the ice-block in the form of a steep-sided hole. The ideal section demonstrates that an alluvial plain, which is built up in front of a glacier, will overtop the ice and include not only morainic debris but also blocks of the ice, and when the glacier melts, the overlapping deposit cannot assume the simple earth slope of the angle of repose, but receives a hummocky morainic appearance as illustrated in the surface from the dotted line at E in Fig. 132. This is also to be noted in Fig. 131.

Eskers. — The term esker is here employed to denote distinct ridges composed chiefly of coarse gravel, angular, subangular, and rounded boulders, and sand, believed to have been deposited in the beds of sub-glacial streams, being phenomena of the radial drainage of the conti-

nental ice-sheet. (See Figs. 133, 134.) Continuous ridges of gravel, denoting subglacial stream channels, are of rare occurrence in eastern Massachusetts. There are numerous curved ridges and terraces of some extent that, without doubt, were formed by gravels deposited from the surface of a waning ice-sheet. The glacial gravels from Bishop's swamp, an ice-block hole at Danvers, supply an example on a small scale. (See Fig. 136.) Many similar examples both large and small, may be found in all parts of Essex County. Typical eskers, continuous for a mile or more, as previously stated, are of rare occurrence.

A nearly continuous esker, broken by post-glacial erosion and stream-cutting, may be traced from Groveland, across South Groveland to the Parker river in Georgetown, and then across Parker river to Four Mile pond, in Boxford. At the northern end of Four Mile pond this esker expands into a rolling sand-plain. On the western side of the pond it again forms into a steep-sided ridge which extends over one mile to the southeast, where it is obliterated by the Pye brook sand-plain in Boxford. This esker is next seen as a continuous ridge at a point about two miles distant and north of Hood's pond in Topsfield. It may be easily followed in the valley occupied by the road-bed of the Boston and Maine railroad to a point near Bare hill in Topsfield, where Mile brook and a series of meadows have cut through and destroyed the formation. This esker is next seen in a hilly pasture on the land of John Perkins, south of Mile brook. Here it becomes very distinct and forms two parallel ridges. It then crosses the Ipswich road and disappears at the bank of the Ipswich river. On the other side of the river this ridge may be traced around the northerly side of Willowdale hill to a point southerly from the site of the Willowdale mill, where it is flanked on the east by a remarkable series of reticulated kames exhibiting both knob and basin topography, many of the iceberg holes now being occupied by small ponds. (See Figs. 135, 138). At the Gwinn farm in Hamilton this esker again appears in a pasture, where the top of the ridge might be observed for a distance of over a mile if it were not for the growth of small trees and bushes which cover it. South of the Gwinn farm (see Fig. 137) it crosses the road and is then overgrown with hardwood trees for a distance of nearly five hundred yards to a narrow swamp. Beyond this swamp the ridge again appears distinctly with very steep sides. At one point it is eighty feet from the top of the ridge to the level of the low land in the swamp from which the esker rises. This section is continuous for over half a mile to the tracks of the Boston and Maine railroad, where recent

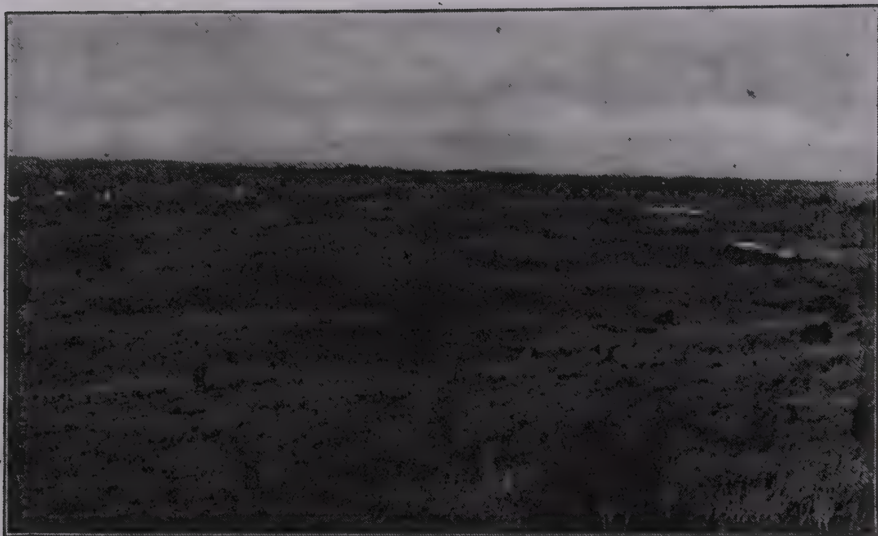


Fig. 129.—"SHEEP BACKS," OR *ROCHES MOUTONNÉES*, AT SOUTH GEORGETOWN.
Small elevations of bedrock covered by drift gravels.

Fig. 130.—"SUGAR-LOAF" HILL OR *ROCHE MOUTONNÉE* AT TOPSFIELD.
Arkose granite conglomerate covered by a thin coating of glacial drift.

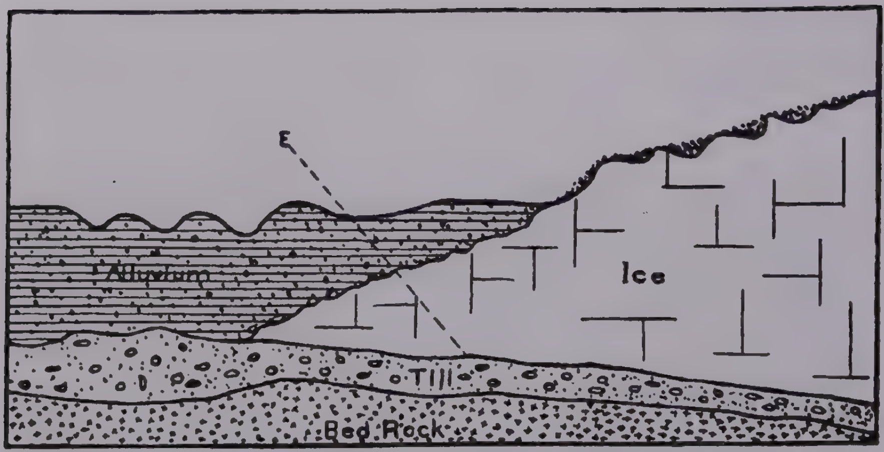


Fig. 131.—IDEAL SECTION OF AN ICE BLOCK HOLE.
The profile indicated by *E*, marks the face of the alluvial deposit after the ice has melted.

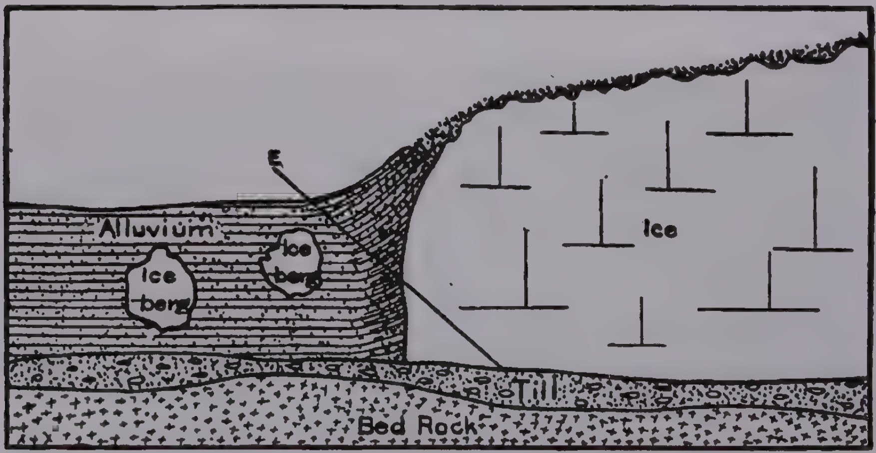


Fig. 132.—IDEAL SECTION OF AN ALLUVIAL PLAIN BORDERING THE FRONT OF A GLACIER.

excavations for gravel have destroyed all traces of it for two hundred yards. Beyond the railroad, the esker continues on the northerly side of a drumlin known as Lummus' hill and extends to the Hamilton and Ipswich road, where the ridge is cut away and replaced by a sand-plain. This plain is occupied in part by the polo grounds. It extends to Miles river and covers the whole area of Wenham and Hamilton as far as the village of Wenham on the west. Across Miles river, the esker becomes a series of low, rolling ridges and kames, which extend in a southwesterly course and follow the bank of Miles river for a distance of a mile to the swamp where the outlet from Beaver pond and Norwood's pond joins Miles river. On the westerly side of this swamp, and south of the rocky hills, there is a remarkable ridge or series of ridges which is without doubt composed of overwash gravels from the ice contact in Wenham lake, for the ridge gravels may be traced continuously to the lake, and are probably of later origin than the esker which is the inner or northerly ridge and follows the base of the hills to the Longham basin. This inner ridge is very steep and high-sided, and in places becomes divided into two or more ridges with deep iceberg holes having small ponds at the bottom. (See Fig. 140.) The esker then winds around Norwood's pond and forms a rolling ridge on its eastern side (see Fig. 139), the main ridge of the esker being on the western side where it is of a low, rounded form showing much erosion on its surface, which is deeply furrowed and in places cut down nearly to its base. Three hundred yards to the southeast, the esker expands into a sandy gravel-plain, which is cut through by a brook, an inlet to Beaver pond, Beverly. From this pond the esker is continuous, with several iceberg holes and short reticulated kames, to Essex street, Beverly, where it divides and passes on both sides of Turtle hill, a large granite outcrop, at the south of which it develops into a rolling sand-plain extending to Beverly cove and Mingo beach.

This is the only continuous esker ridge in Essex County. There are many short ridges, more probably kames and ancient barrier beaches or tombolas, which, with a stretch of the imagination may be connected as parts of one and the same ridge or esker.

Beaver pond in Beverly is without doubt an ice-block hole, as on the southeastern side of the pond there is found a steep incline of morainic drift and kame gravels. Norwood's pond was formed artificially by the construction of a dam between the Wenham-Beverly esker and a kame terrace at the east.

In the town of Danvers, southwest of Nichols' hill, a drumlin, there is an

esker which may be readily traced in a serpentine course, from Nichols' hill to Beaver brook and then southeasterly to Putnam's mill pond, where it skirts Walnut Grove cemetery on the south and crosses Endicott street to the John Bates farm, where it is cut through by Water's river. Across the river, at the foot of Gardner's hill, it winds along the bank of Porter's river into North Salem, and, crossing the North river, follows in a somewhat serpentine course, Essex street to Boston street; then sweeping to the south between Canal street and Lafayette street, it forms a series of kames on the Derby and the Pickman farms lying southwest of the State Normal School in South Salem. Across Forest river it becomes a series of reticulated kames and ridges on both sides of Legg's hill (see Figs. 141, 143, 144) and, expanding to a plain at the east of Beach Bluff in Marblehead, it sinks into the sea at Phillip's beach in Swampscott.

A ridge which is possibly a remnant of an esker may be seen about one mile east of Kimball's pond, in Amesbury. This ridge, which is quite serpentine in outline, crosses the source of Bailey's brook and continues parallel with it and on its easterly side to the Amesbury and Haverhill road. At the north side of the road there are good examples of iceberg holes and short reticulated kames with the usual knob and basin topography to be seen in a region where icebergs have been buried in glacial gravel. Across the road on the Davis farm, the remnant of the esker may be very plainly seen in the form of a circular steep-sided ridge, which extends to the northern bank of the Merrimac river. On the other side of the Merrimac, east of "The Laurels" and near the old ferry road from Newburyport to Salisbury Point, kames and iceberg holes become very prominent features in the landscape. From the ferry road to High street in Newburyport, the whole surface of the area, which is about a mile square, is a rolling sand-plain, but the eastern part of "Grasshopper plain," at the upper end of High street, is a broad-topped esker which extends the whole length of High street to Old Town, in Newbury, and out into the tidal-marsh north of Parker river. There are several sections cut through this esker on High street near Belleville, which show that it rests upon boulder-till and earlier gravels.

Another esker enters Essex County from Newton, New Hampshire, between Brandybrow hill and the "Highlands" in Merrimac. This esker passes over the summit of Red Oak hill at an elevation of three hundred and twenty feet above mean sea-level and winds in a northeasterly direction. It is next seen on the west bank of Cobbler's brook and extends to the Merrimac. Across the river in West Newbury, the

Fig. 133.—THE LONG ESKER NEAR DODGE STREET, NORTH BEVERLY.

Fig. 134.—THE LONG ESKER NEAR DODGE STREET, NORTH BEVERLY.
View looking northwesterly across Dodge street.

Fig. 135.—SERPENTINE ESKER AT WILLOWDALE IN HAMILTON.

Fig. 136.—BISHOP'S SWAMP, DANVERS, AN ICE-BLOCK HOLE.
View from the base of Nichols' hill showing the gravels deposited from the surface of glacial ice.

continuation of this esker may be traced around Long hill to Indian river, where there is a break of nearly four miles. The entire surface of this region is covered with hard, compact boulder-till, with a few, comparatively small rounded masses of gravel resting upon it. Short ridges, which may represent remnants of the esker, may be noted; one, south of Archelaus hill; a second, southeast of Ilsley's hill; and a third on Moody street, which extends to Byfield village. At the southeast, a discontinuous ridge follows the west bank of the Parker river out into the tide-water marsh lying east of the Fatherland farm in Byfield. The ridge is next seen at the west bank of the Mill creek near Glen mills, where it is nearly continuous for about a mile, but is divided into two distinct ridges at Ox Pasture brook. At the south and southeast it is cut off, and a beach sand-plain covers the region on which the village of Rowley is built. Sand-ridges and plains extend southeasterly between the drumlins, Mussey hill (see Fig. 146) and Prospect hill, in Rowley, to Bull brook and the village of Ipswich. South of the brook there are a few short ridges of water-washed gravels underlaid by clay-beds. No bouldery cross-bedded esker gravels are found southeast of Rowley, so it may be presumed that the course of the esker was easterly and into Ipswich bay.

In the northwestern part of the County, an esker enters Methuen from Salem, New Hampshire, a mile east of the Spicket river. Pursuing a winding course it crosses the river and follows its west bank down the valley to Stevens' mill pond, and beyond it in a southwesterly direction to the Merrimac river. In South Lawrence, the sand-ridge divides into several distinct short ridges reaching into West Andover, one being the well-known "Indian ridge." South of "Indian ridge" the esker is lost in post-glacial sand-plains and short curved terraces. Near Pomp's pond it becomes clearly defined, and may be easily followed half a mile beyond Ballardvale, where it disappears in a sand-plain, probably an inland sea beach which covers an area of about two miles square and extends to Reading in Middlesex County. The composition of these sand-terraces is of the same grayish-white fine sand that is found on beaches along the coast, and does not in the least resemble the reddish sand of the esker and ice-contact series, the sands and gravels of the esker at Hamilton and Beverly in particular. The southwesterly part of Andover is covered with a nearly horizontally-bedded sand which extends downward almost to the surface of the bed-rock on top of which is boulder-till, but seldom more than a few feet in thickness.

Evidences of Sea Beaches at Inland Points. — During the Interglacial or Champlain period, there was a corresponding subsidence of the land surface which again changed the climate from arctic to boreal. During this period the ice-cap melted and wasted away, and the land sank below the level of the sea to a depth of two hundred feet or more. This depth of subsidence is proved by finding in our marine clay-beds, specimens of fossil mollusks which live at that depth in the high Arctic seas.[1] Therefore it may be presumed that these mollusks, which are of the same species and size as those found in Norway, lived at the same depth on our coast during this Interglacial period.

The subsidence during the Champlain period caused the whole land surface, including the highest peaks of outcropping ledges in the County, to sink below the surface of the sea, and the ledges and hills which had been cut down, rounded, and smoothed by glaciation, were then stripped of their debris by the action of the waters. The results of wave and sea action are to be seen in many parts of the County. Sand and gravel beds, comparable only with sea beaches, are often found in localities remote from ice contact. These are composed of coarse gravels in which all the pebbles and stones are rounded and smoothed as in sea-washed shingles. Some ridges are also composed of wave-washed sands, round beach pebbles, and stones of exactly the same material as those found to-day in making an excavation through the barrier of a sea beach. Examples of such debris may be found in all parts of the County. At Reading, in Middlesex County, there is such a deposit which extends toward the north and covers a large part of Wilmington and Andover. Here the fine silts and sands are water-laid, and the coarse gravels contain stones and pebbles worn round and smooth like similar deposits on the sea beaches. Numerous road-cuttings and gravel-banks reveal the fact that the bedding of these deposits is horizontal with hardly a trace of cross-bedding, save in some restricted areas. The presence of a shearing or cross-bedded area in the otherwise horizontally-bedded sands is explained by the flow of cross and counter currents below the surface. Several of the ridges at Andover are dotted with numerous large boulders, and where cuttings have been made, these boulders are found to be equally abundant below the surface and intermingled with the fine water-laid sand and silt of which the ridges are composed. Numerous cross-sections of these ridges, with hanging boulders, may be seen along the road-bed of the Boston

[1] Professor Brögger — "Late and Post-Glacial Changes of Level in the Region of Kristiania," pp. 156–159.

Fig. 137.—SERPENTINE ESKER ON THE GWINN FARM NEAR WILLOWDALE IN HAMILTON.

Fig. 138.—SERPENTINE ESKER AT WILLOWDALE IN HAMILTON.
Illustrating reticulated kames, and knob and basin topography. The small pond is at the bottom of an ice-berg kettle hole.

Fig. 139.—NORWOOD'S POND, NORTH BEVERLY, HAVING ESKER TERRACES ON BOTH SIDES.
View from the main terrace

Fig. 140.—DOUBLE TERRACE ESKER ON THE NORTH SIDE OF LONGHAM BROOK, WENHAM.
Showing a kettle hr e.

and Maine railroad in Wilmington and Andover. There is but one explanation for the presence of boulders in these fine silts and sands. They must have been dropped from the bottom of floating ice, as this inland sea was not of sufficient depth to float an iceberg large enough to carry a load of these boulders.

Sea-worn gravels may be seen in the numerous road-cuttings along the line of the electric road between Georgetown and South Groveland. Here the same rounded beach-worn gravels appear horizontally-bedded with the sands, but exhibiting no trace of cross-bedding, even in sections of ridges.

Grasshopper plain, west of Belleville, at Newburyport, is another example of an inland marine beach. The fine sand and slits on the surface vary from a few feet to ten feet in depth, and below these sands, sea-worn pebbles of slaty rocks predominate, rounded on their edges like the slaty pebbles found at Boar's head and Hampton beach in New Hampshire. The conclusion is inevitable that these deposits of sand and sea-worn pebbles indicate old sea beaches that were formed during the Interglacial and Champlain epochs of the Pleistocene period.

Subglacial Drumlins. — Boulder-till, the grand moraine of many authors, is a compact, unstratified mass of glacial debris, composed of clay, sand, gravel, pebbles, and boulders, mixed together in a heterogeneous mass without stratification of its members. (See Figs. 145, 147, 148, 150.) It was formed under and incorporated in the basal portion of the ice-sheet. Some of the boulders are glaciated — smoothed or polished and scratched with fine lines or striæ on some parts of their surfaces. Small boulders and pebbles are invariably glaciated. The bed-rock, in all parts of the County where it can be examined, is covered by a layer of this boulder-till, varying in thickness from a few inches to over one hundred feet.

Drumlins are composed of two kinds of materials. The upper portion, which is from six to forty feet in thickness, is usually found to be comparatively loose reddish-yellow till, with numerous boulders which frequently are of large size. This kind of till is thought to have been formed in and on top of the waning ice-sheet at the close of the Glacial period, and at its final disappearance, to have been deposited on top of the true ground moraine or boulder-till, and thus the upper portion which is exposed to view is englacial and not true subglacial till. The lower portion of the drumlins is composed of blue clay, sand, gravel, and boulders, without any system of arrangement of the different component parts. Occasionally the small boulders and pebbles are somewhat triangular in shape, and are scratched, smoothed, and sometimes polished on all their sur-

faces as if they had often served as abrading tools while frozen into the lower surface of the ice-sheet; from that position to be dislodged and, after rolling over and over, again to become frozen into the ice, thereby exposing a fresh surface to continue the process of smoothing and scouring the bed-rock over which the glacial ice passed, until at last they were deposited in the boulder-till where we find them to-day. A drumlin near the Shawshene river at North Andover contains many such triangular, scratched, and smoothed boulders and pebbles. (See Fig. 126.) In other drumlins, these forms of scratched stones are rare, and smoothed and scratched blocks with rounded edges are the rule. Such blocks are rarely composed of hard rocks. Small pebbles of quartz, usually subangular in form and somewhat smoothed upon their surfaces, are often found in the boulder-till. Without doubt these were the tools that produced the deep grooves, scratches, and chatter-marks so often seen upon the surfaces of the granite and diorite bed-rocks.

In Essex County, there are one hundred and seventy-three drumlins, and one hundred and seven thousand, five hundred and twenty acres of boulder-till soils which are very fertile for the agriculturalist. Hog island, in the town of Essex, is a typical specimen of a drumlin. (See Figs. 145, 149.)

Wash-Plains. — The mode of deposition of the wash-plains in this region affords a clue to the relative areas of stagnant-ice and live-ice during the retreat of the glacier from this area. The conditions demanding stagnation are found in the numerous ice-block depressions and wash-plains with heads which show no forward movement of the ice-sheet, either by the failure of shoving in the gravels, or by the lack of morainal deposits in the terrace at the heads of the wash-plains.

The facts demanding live-ice, at intervals during the retreat, are the lines of boulder-belts, or positions, marking halts of the ice-front, during which backward melting equalled forward movement.

The boulder-belts at Cape Ann and at Newbury, in the Byfield area, were probably deposited when the ice-cap at the north was still live-ice, in which there was a forward movement and also general retreat. Every forward movement of the ice-sheet would reduce and obliterate all former wash-plains laid down during the retreat of the ice over the area, and except in areas far in front of the ice advance, wash-plains and delta-fans would be built up on former wash-plains, thus making the composite structures we find to-day reaching in a north-northwesterly course across the County and well into New Hampshire.

In South Salem, on Broadway, masses of boulder-till and clay are

Fig. 141.—KAMES AND KETTLE HOLES NEAR FOREST RIVER.
Salem.

Fig. 142.—STEEP-SIDED ESKER WEST OF NORWOOD'S POND.
North Beverly.

Fig. 143.—KNOB AND BASIN TOPOGRAPHY, SHOWING KETTLE HOLES SOUTHWEST OF THE "DUNGEONS" IN MARBLEHEAD.

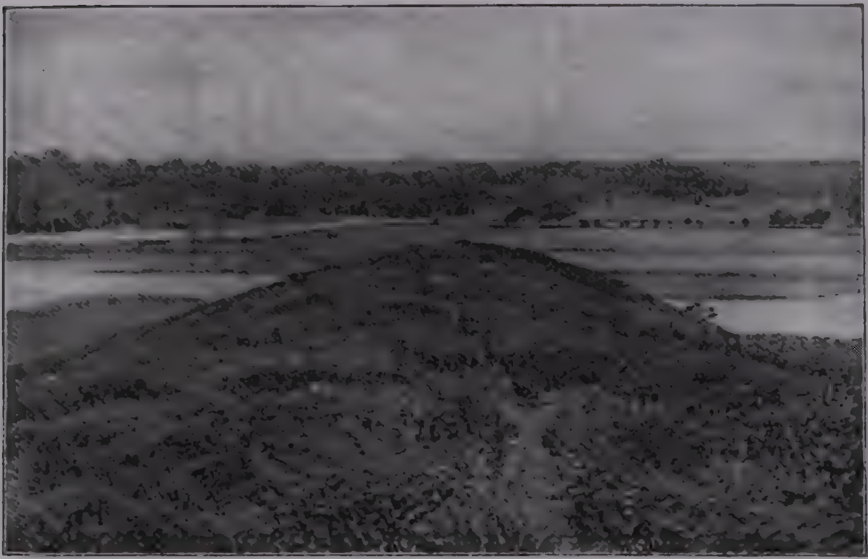


Fig. 144.—GLACIAL TILL AND GRAVEL CONE ON THE SOUTH SIDE OF FOREST RIVER, SALEM.

found between gravels of an earlier and a later wash-plain, showing at this point the retreat of the ice when the lower gravels were deposited, and an advance when the boulder-till was formed upon the earlier gravels, and then a later retreat in which the surface deposit or thin sheet of gravel and sand was laid down.

Without doubt there are many such local deposits near the sea-coast showing two or more advances and retreats of the glacial ice-sheet or, at least, deposits caused by local glaciers which have advanced, and deposited boulder-till, and then retreated during a series of warm seasons when over and outwash gravels were equally laid down; but it is very doubtful if such retreats and advances occurred away from the immediate seashore. In Lawrence, Haverhill, and Andover, there has been extensive cutting away and levelling of hills for streets, but the cross-sections have not shown examples proving more than one advance.

It would therefore appear that when the drumlins and boulder-till were deposited, and the ice-sheet had retreated from the region, the kame-gravel wash-plains and other phenomena of the drift were laid down. This is clearly due to the Champlain subsidence and the later elevation of the land surface.

Kames and Ice-block Holes. — Wash-plains appear in the form of gently sloping areas, composed of stratified gravel and sand, deposited along the ice front. Many wash-plains are interrupted by depressions, or amphitheater-like hollows, illustrating the formation of "kettle holes" and the slope of kame-terrace gravels in front of the retreating ice-sheet. (See Figs. 154, 155.) The term kame is used in the generally accepted sense, as designating deposits, chiefly of sand and gravel, having a knob and basin topography, and formed at the margin or periphery of the ice-sheet, or in front or over ice-blocks. Examples of ice-contacts left at intervals to show the retreat of the ice in its final melting are seen in various parts of the County. One excellent example, in which there are a series of ice-block holes on a small scale, is the overwash gravel- and sand-plain in Marblehead, near the Salem boundary line. This contact was formed when the retreating ice front was in Forest river, reaching out into Salem harbor. The ridge marking the contact is irregular in outline, and extends on the south side of the bed of the river around Legg's hill, a massive outcrop of hornblende diorite rock that rises one hundred and sixty-five feet above mean low water.[1] (See Figs. 156, 157, 158.)

[1] An ice-block hole near Legg's hill is now represented by a small pond known as Legg's Hill pond. This pond, which is fast disappearing under the swampy peat that is

These numerous crater-like hollows, locally called "dungeons," and amphitheater-like depressions, mark small ice-block holes when berg-ice, detached from the ice front, became covered by the overwash sand and gravel, and upon the melting of the ice-block the gravel sank and the depressions appeared.

The great Wenham swamp, in the towns of Wenham and Hamilton, an area of some two thousand acres, was formerly occupied by a large ice-block, which extended northward into Topsfield. At the south and east is the overwash sand-plain, across which Cherry and Arbor streets extend. Around Muddy pond and Pleasant pond the contact assumes the form of cones and short ridges, with steep sides dipping into the swamp. On either side of Arbor street are "kettle holes" all having small tarns at the bottom. (See Figs. 161, 162.) The sand-plain extends southeasterly across Wenham and into North Beverly, and on the east it covers the larger part of the town of Hamilton. From Cherry street, in Wenham, to Mapleville, West Wenham, the gravel ridge on the shore of the swamp is continuous for about a mile, and everywhere throughout its length, exhibits the varying slope of the ice-contact, and, at the outer end of the swamp, knob and basin topography.

Cedar pond, in Wenham, a small ice-block hole, is surrounded by overwash gravels in cones and short ridges reaching to the shore of Wenham lake. On Enon street, in North Beverly, the steep-sided ridge sloping down to the lake, marks with great distinctness, the ice-contact with its overwash plain, which extends across North Beverly to the seashore.

The ice-block which formed Wenham lake was probably continuous in the valley now occupied by the Miles river, the outlet of the lake, and extended to the Longham basin and East Wenham. (See Fig. 165.) This contact in the Longham region is peculiar, in that the ice occupied a comparatively narrow area, and must have extended southeasterly for over a mile, forming on both sides fine examples of overwash ridges,

forming around its borders, is situated in Salem near the Salem and Swampscott town line and southwest from the summit of Legg's hill. (See Fig. 159.) Crooked pond, Boxford, is an ice-block hole now represented by two small ponds. This pond is fast disappearing, having been reduced in area more than one half during the past one hundred years by the growth of vegetable matter. Sphagum moss grows very rapidly at the water's edge and reaching out into the pond offers a resting place for wind-blown soil, in which marsh plants soon obtain a foothold, and in a few years swamp-bushes and trees commence to grow and form a strong network of roots upon the surface of the pond, which may be walked upon with perfect safety. These ingrowing swamps formed over the surfaces of ponds have been called "quaking bogs," from the tremulous wave-like motion produced when they are walked upon. (See Fig. 160.)

Fig. 145.—HOG ISLAND, ESSEX, AT LOW TIDE.
A typical drumlin showing adolescent grass-grown scarps caused by land-slides.

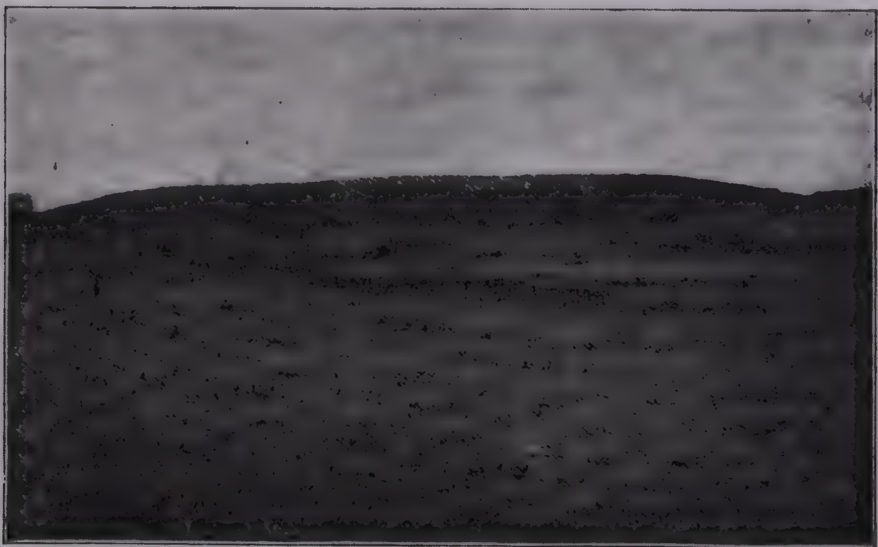


Fig. 146.—MUSSEY HILL, ROWLEY.
As seen from the rolling sand-plain towards the southwest.

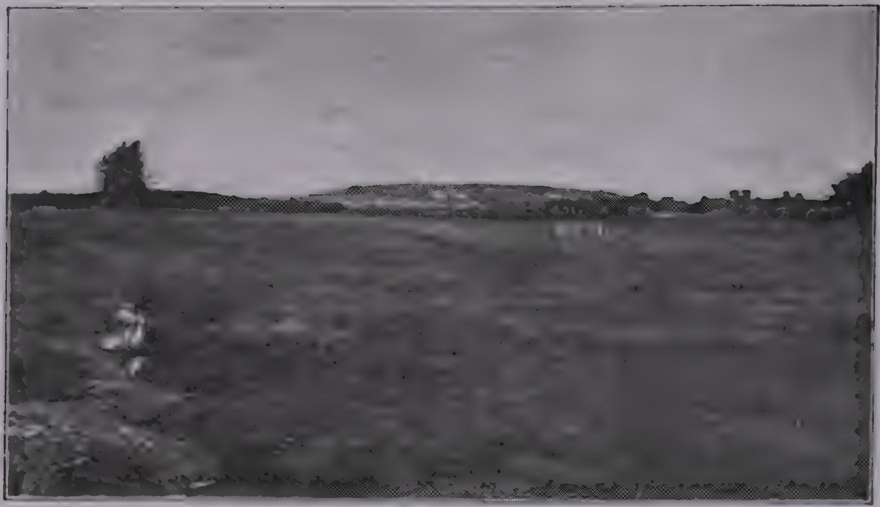


Fig. 147. — OLD TOWN HILL, NEWBURY.
View from the southwest across the tidal marsh.

Fig. 148. — EAGLE HILL, IPSWICH.
A small drumlin, with base cut by wave-action.

or kame terraces, with characteristic knobs and basins, sloping to the contact with the ice in the valley. Northwest of the main area of Wenham swamp there is a smaller swamp known as Leach's swamp, on the southeastern extension of which is built a sandy gravel-plain, over which Wenham street is constructed for the distance of about three hundred yards. The easterly part of this street is built upon the edge of a sharp bank which is an ice-contact, somewhat circular in outline, that develops into a sharp ridge (see Figs. 163, 164) on the edge of the swamp for about two hundred yards, and without doubt, marks an extension of the contact into the swamp. A considerable plain of coarse gravel extends from this contact, and is succeeded by one composed of fine sand, one half a mile further to the southeast.

In the Wenham swamp area, there are several islands of fine sand. When the ice-block that occupied this area became very old, these sands were probably washed into large holes in the ice, from the surface of overwash gravels. One of these, Turkey island, is the remnant of a drumlin, and is composed of boulder-till. Its low, flat, upper surface is covered by a thin sheet of water-laid sand and gravel, and at the northern edge it is very steep, and probably marks an ice-contact.

At the south of Wenham swamp, across Asbury Grove and Wenham, the outwash gravels join the gravels of the great wash-plain which covers nearly the whole area of Wenham and Hamilton. Cutler's pond, in Hamilton, is probably the eastern extension of the ice-block of this area.

The wash-plain gravels which cover the region known as the "back side of Hamilton," and also part of Ipswich, show ice-contacts on the northern bank of the Ipswich river from Mile brook in Topsfield to Miles river, the outlet of Wenham pond. The present bed of the Ipswich river, therefore, was the front of the retreating ice-sheet in this region when this sand-plain was deposited. At the north of Dummer's hill, between Bartholomew's hill, Scott's hill, and Bush hill, Bull brook takes its rise in Pine swamp. Probably local glacial ice formed here the kame topography of short ridges, cones, and sand-plains which extend southeasterly to the Ipswich river.

Near Mill river in Rowley and Georgetown, at the west of the Ipswich area, is a noted region for kames, knobs, and basins. In Georgetown, from Long hill to Redshank hill, the longer axes of these kames are generally in a northeasterly to southwesterly direction, and across the line of glaciation of this region. The outward sand-plain at the southeast, extending across Rooty plain and Linebrook parish, to Topsfield, is the work

of overwash and outwash gravels, to be expected in front of an ice-contact. "Kettle holes" are seen in many parts of this area, and many of the larger individual holes have well developed overlapping sand and gravel outwash on top of the general sand-plain. Some of these ice-block holes are of remarkable depth, with very steep sides. One is situated about half a mile north of the Boxford, Georgetown, and Rowley, town boundary lines, on the division line between Georgetown and Rowley. Others occur south of Mill river on the Rowley and Boxford boundary lines. There are several remarkable "kettle holes" in Linebrook parish, and between Howlett's brook and Mile brook in Topsfield, there is one that is forty feet deep. On the John W. Perkins farm in Topsfield, near Mile brook, is a series of remarkable kame terraces with very steep sides, extending in a westerly direction. These terraces are the ridges which were left, after the berg-ice in front of the large ice-block at Hood's pond had melted. The steep banks of gravel and sand on the southerly shore of this pond are excellent examples of ice-contacts, exhibiting the accompanying flood-plain of sand and gravel at the south-east, extending across Topsfield.

The Chebacco lakes in Essex, Hamilton, and Wenham, are also ice-block holes, with outward overwash sand-plains, short gravel ridges, cones, and berg-ice holes deposited in a south to southwesterly direction. Knowlton's swamp, from Hamilton Four Corners and parallel to Eastern avenue in Hamilton, is a typical ice-contact of water-laid sand and gravel, sloping abruptly to the low ground of the swamp. It is over one half a mile long. The wash-plain of gravel and sand deposited outward along this ice-front; the short kame-like ridges, cones, and lobate fans of sand fringing outward and inclosing areas around Beck's pond; the sand-plain at Woodbury's Station on the Boston and Maine railroad; and Beech plain in the Hamilton and Essex woods, all are portions of the wash-plain extending from Knowlton's swamp.

Bound pond, Gravelly pond, and Coy's pond, in Hamilton and Wenham, are also ice-block holes having contacts of sand and gravel on their south-easterly shores that develop outward into sand-plains and kames, filling a large part of the lowlands between the outcropping granite ledges. At Essex and Manchester, among the granite hills, there are numerous short drainage-creases usually extending in directions east or west of the line of glaciation, where water from the melting ice, in its final retreat from the region, washed out the till, sand, and gravel, leaving these creases filled with rocks and boulders. (See Fig. 166.)

Fig. 149.—HOG ISLAND, ESSEX, AT HIGH TIDE.
The rocks in the foreground are the remnants of a stone wall on either side of a road which has been submerged because of subsidence.

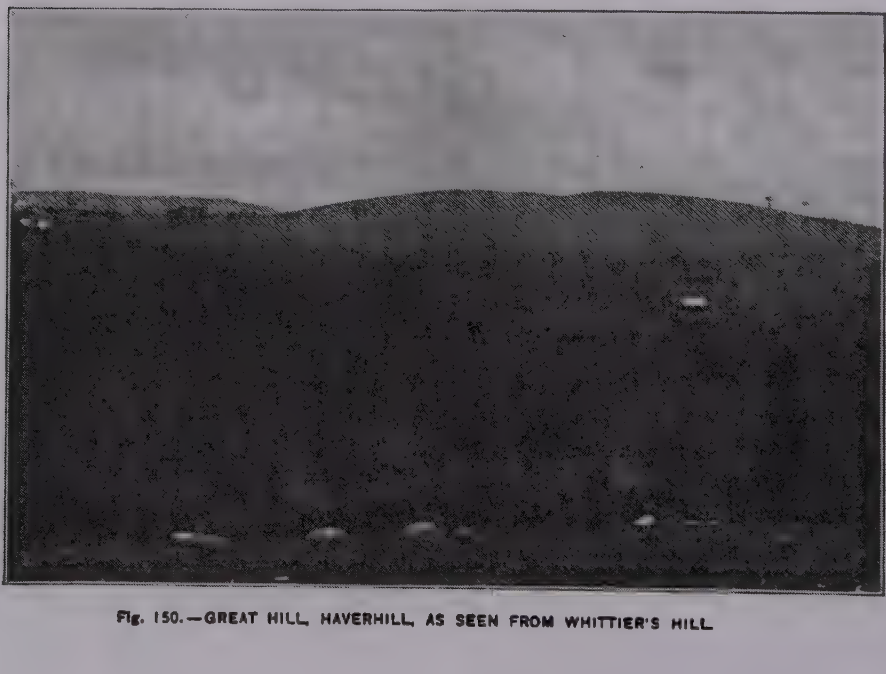


Fig. 150.—GREAT HILL, HAVERHILL, AS SEEN FROM WHITTIER'S HILL.

Fig. 151.—DRUMLINS ON JEFFREY'S NECK, IPSWICH.
As seen from Eagle hill.

Fig. 152.—TURKEY HILL, A DRUMLIN AT EAST HAVERHILL.

The sand-plain extending southeasterly from Prospect hill in Rowley and across Ipswich, is formed in front of an ice-block hole in Pine swamp. The outwash sand-plains and kame ridge at the southeast of the Metcalf rock diorite outcrop, form a nearly complete circle with a gravel cone in the center. Bull brook and its tributaries, in Post-Pleistocene times, cut down and removed to clayey boulder-till the sand-plain in the valley. Beyond these valleys, sand and gravel ridges and rolling sand-plains extend southeasterly to the Ipswich river. (See Fig 146.)

Post-Pleistocene Sand and Gravel. — South of the village of Ipswich, fringing out in fan-shaped lobes from Heartbreak hill, and extending to the northeastern part of the town of Essex, is an area showing boulder-till ground moraine, surrounding ridges and plains of sand deposited during the Champlain period.

In the Newbury-Byfield district, a boulder train extends from the salt marsh at the west of Kent's island, across Byfield to Georgetown, a distance of six miles in a straight line, but following an irregular course of over ten miles. The trend of the boulders is from the northeast to the southwest and marks a halting place of the glacial ice in its retreat northward. These boulders rest upon the surface of the ground moraine of boulder-till and probably were once covered wholly, or in part, by the sand, gravel, and clay that have been washed southward during interglacial times, when the land surface was submerged, and now form the plain known as "the Rye field" on which the car houses of the Boston and Northern Electric railroad are built. A cross-section through this sand-plain shows the surface for a depth of two feet, to be composed of fine sand and silt, probably deposited in shallow water; below this appears four feet of coarse sand and next is found a deposit of very coarse gravel and well-rounded stones with no sand — a typical sea beach or old lagoon. Surrounding this ancient lagoon, at the south and east, and extending westerly from the South Byfield meeting-house, there is a series of sand-dunes, more or less grass-grown, only to be compared with the Post-Pleistocene dunes in process of formation at the present time at Ipswich. This plain covers an area about a mile square and is from six to ten miles inland from Plum Island river. Near Mill river in Rowley, and south of this plain, beds of clay and fine sediment are deposited, occupying the entire area to the Newburyport turnpike at Chaplinville.

The live sand-dunes in "the Rye field" locality are the finest examples of inland sand-dunes to be found in the County. They encircle a lagoon through which meanders Wheeler's brook, probably a tide-water creek, at

the time the dunes were forming. Many of these sand-dunes are grass-grown and in places are covered with forest trees and bushes. They are undoubtedly of Pleistocene age and were formed during the Terrace or late Champlain period. (See Figs. 167, 168.)

The northern and western sides of Town hill, in Ipswich, are surrounded by grass-grown sand-dunes and westerly from the dunes, covering the Ipswich poorfarm, there is a sand and gravel plain of considerable extent on which is located Brown's brick clay-pit. This plain, underlaid by clay, is comparable only with the sea-water lagoons or tidal marshes lying easterly from Town hill at the present day. A series of these fringes of grass-grown sand-dunes, with lagoons west of them, may be traced across the whole County and are undoubtedly phenomena of the Terrace epoch. Such a formation exists at Topsfield near the junction of Fish brook and the Rowley Bridge road. Westerly from these dunes, small lagoons, now swamps overgrown with larches, extend into Boxford. The sand- and gravel-plain in this direction is on both sides of Fish brook and covers an area about two miles square. Sand-dunes are also to be seen east of Pentucket pond and Rock pond in Georgetown. These dunes extend in a circle to South Groveland where the old lagoon to the westward is very pronounced and easily traced over the entire area. Other grass-grown dunes are found in Andover and Lawrence.

The Merrimac river was probably a halting place of the glacial ice in its retreat northward, for its southern shore, from the mouth of the Parker river to Pipe Stave hill, marks typical ice-contacts of morainal-till and overwash gravels capped by sand and silt. High street, in Newbury and Newburyport, is laid out upon the top of the terrace formed by this ice-contact, a section of which shows it to be composed of boulder-till and clay-beds resting upon the glaciated bed-rock of quartz augite diorite in varying depths. At Grasshopper plain it is at least fifty feet in thickness, and is covered by twenty feet of coarse gravel with twenty-five feet of fine sand at the surface. This fine sand is creased by a number of steep-sided valleys or drainage-creases extending in a southerly direction to the Little river clay-beds in Newbury. A section of this terrace across High street (see Fig. 169), extending from the river through Green street to the frog pond by "the Mall," gives boulder-till on High street at an elevation of eighty feet above tide water. The frog pond is the site of a small detached iceberg that was buried in the morainal-till. South of "the Mall," the overwash and outwash gravels have formed a series of cones and short ridges or kames of sand and gravel extending southeasterly into

Fig. 153.—WHITTIER'S HILL, A DRUMLIN AT HAVERHILL.

Fig. 154.—ICEBERG OR KETTLE HOLE IN THE "DUNGEONS." Marblehead.

Fig. 155.—ICEBERG HOLES IN KAME GRAVELS NEAR LEGG'S HILL, SOUTH SALEM.
Legg's hill, a wave-swept outcrop of hornblende diorite, may be seen in the distance.

Fig. 156.—ICEBERG HOLE IN OVER-WASH GRAVELS.
Also showing a short kame within the hole. The "dungeons," Marblehead.

Newbury. The tracks of the Boston and Maine railroad cut through these gravels on the west, and the track of the City Freight railroad cuts through them on the east. In 1898, this cut exhibited a good section of the deposits some three hundred yards in length. The gravels and sands dipped to the south at an angle of 35° and were capped by a deposit of clay having sand partings every few inches. The greatest depth of the gravel and sand was forty feet. North of the center of the hill there was a dip twenty feet deep filled with clay having fine sand partings, and under the clay, at the bottom of the dip, there was a mass of peat, probably the site of an iceberg in the gravel before the clay was deposited.

South of Oak Hill Cemetery there is a "kettle hole" which a few years ago contained a floating island.[1] In the spring of the year when the melting snows raise the water level, this pond covers an area of about a quarter of an acre. It is a typical small ice-block hole with southeastern outwash sand and gravel kames probably deposited in cracks or gorges in the glacial ice which filled the whole valley of Little river.

High street, in Newbury, is built on sand and gravel that cap clay and till, a typical beach barrier sloping back to the lagoon at Four Rock creek. The debris is washed away from the outcropping ledges that rise above the boulder-till covering the surface. This beach barrier with the lagoon on the shore side occupied the whole of the Little River valley and was continuous on the southwest around Old Town, and Little Old Town hills. A gorge between these hills, now filled with coarse waterworn gravels on top of boulder-till, was the drainage outlet to the southeast. In front of the gravels, the outwash sands spread out over Newbury Old Town, to the mouth of Parker river where steep banks and fringing lobes extend into the salt marsh overlapping the boulder-till.

Eagle hill, on Kent's island, in Newbury, is composed of slate rock, well glaciated, polished, and scratched with fine striæ. On the north side of the hill, in the shallow bed of Little river, and only to be seen at very low tide, is the longest and deepest glacial groove known to exist in Essex County, and probably in New England. This groove is cut southeast and northwest in a slate and sandstone, somewhat metamorphosed into a hard rock, and is eighteen inches wide, six inches deep, and forty feet long. Sections of it, extending towards the southeast, may be traced for nearly five hundred yards along the shore of the island, after it leaves the bed of Little river. Another deep groove occurs on the east side of Green street, Newbury Old Town, near the corner of Han-

[1] See *American Journal of Science* (1827), Vol. XII, p. 122.

over street. It is cut in a quartz diorite ledge, and is eight inches deep, twenty-eight inches wide, and thirty feet long. (See Fig. 170.)

A well-marked ice-contact, showing a halting place in the retreat of the ice, was formed in what is now Hampton Falls river in New Hampshire. From this contact, all the glacial gravels with berg and small ice-block holes may be traced across Amesbury and Salisbury. (See Fig. 172.) A swamp between South Seabrook and Salisbury shows a good ice-contact on the southern edge, with overwash and outwash kames and sand-plains extending across East Salisbury and thinning out near the salt marsh. East Salisbury is a typical sand-plain, with numerous sand-dunes marking a former beach barrier.

In Pelham, Windham, Salem, Atkinson, Kingston, and Newton, New Hampshire, towns joining Essex County on the north, a series of ponds, whose trend is from the northeast to the southwest, were sites of masses of glacial ice, and the waters formed from the melting of these great bodies of ice, drained southward and carried sand and gravel across the whole area of these towns and filled the valleys between the drumlins in Essex County, north of the Merrimac river.

Kimball's pond, in the towns of Amesbury and Merrimac, is an ice-block hole where a large mass of ice was partially buried by drift gravel and sand from the drainage in front of the retreating ice in New Hampshire. On the southeastern shore of the pond there is a remnant of an ice-contact composed of bouldery gravels with outwash sand covering the east side of Pond hill and the western part of Amesbury, and having kames which expand into sand-plains, cones, and terraces of gravel. An ice-contact was formed in the Powow River valley, south of Ring's hill in Amesbury, where moraines of till and kame terraces of sand and gravel cover the region. Captain's pond, in Salem, New Hampshire, is the site of a block of glacial ice with a southeasterly contact. A moraine of clayey sand and gravel forms the shore of the pond and outwash gravels and sand fill the valley between Ayer's hill, in Haverhill, and Spicket hill in Salem, New Hampshire, and extends southward on both sides of Hawkes' brook in Methuen to the Merrimac river. The Spicket river during its southwesterly course from Spicket hill in Salem, New Hampshire, to the town of Methuen, occupies the site of a former ice-contact, for the present river valley would have been parallel to the front of the retreating glacial ice. The present course of the Spicket river in Methuen and Lawrence, is probably in a drainage-crease which ran from the front of the glacial ice when it occupied this area. Kames and ridges which

Fig. 157.—OVER-WASH GRAVELS, ICEBERG HOLES, AND SHORT RETICULATED KAMES.
Winter scene at the "Dungeons," Marblehead. Legg's hill at the left.

Fig. 158.—WINTER SCENE AT THE "DUNGEONS," MARBLEHEAD.
Legg's hill at the right.

Fig. 159.—LEGG'S HILL POND, SALEM.
An ice-block hole nearly filled by peat.

Fig. 160.—CROOKED POND, BOXFORD.
An ice-block hole which has become a nearly filled pond. Bald hill is seen in the distance.

expand into lobate sand-plains, and cones resting upon boulder-till, cover the town of Methuen on both sides of the Spicket river, extending across Lawrence and South Lawrence into North Andover. A boulder-train or terminal-moraine in the southwestern part of Methuen, half a mile east from the Dracut boundary, marks a halting place of the glacier. The drainage from the front of this moraine must have followed the present course of the Merrimac river, as across the river in the western part of the town of Andover, the whole surface of the region from Wood hill to South Lawrence is covered by boulder-till. From Wood hill to East Lawrence fine sand and river silt occur on each side of the river in a belt one eighth of a mile wide, and a thin coating of this deposit covers the boulder-till in parts of the area across West Andover. Upper-till, composed of clayey sand and gravel with numerous boulders, some of which are of great size, may be seen in all the railroad cuttings, especially along the Lowell and Lawrence branch of the Boston and Maine railroad. These boulders were deposited from the lower part of ice-floes, when the area was submerged below the surface of the sea, the water afterwards washing out most of the clay and leaving the sand, gravel, and boulders as found to-day.

A large part of the present surface of Andover owes its sculpture to the cutting of stream-valleys in glacial sand-plains, thereby leaving residual ridges. Many of these valleys are paved with well-rounded stones and boulders. An excellent example of these ridges may be seen along the line of Lowell street between Hackett's pond and Frye's Village in West Andover.

Lake Cochichewick in North Andover, formerly known as Great pond, is the site of a large ice-block that probably extended across the Merrimac river. The lake seems to have been ploughed out during an advance of the ice as indicated by its depth below the surrounding land surface. Overwash gravels and moraines of boulders with drainage-creases extend from the lake towards the south and southeast, proving that its drainage was in that direction during the melting of the ice to the present level of the lake. These drainage-creases occur on both sides of Bear hill and lead down to the great sand-plain which covers the valley between Mill's hill and Bear hill. The area between Marble Ridge station and Ingall's station, on the Boston and Maine railroad, and the valley of Boston brook, in Middleton, and extending to Fish brook in Boxford on the east, is covered with short terraces, probably old sea beaches, which coalesce with sand-plains, having grassed-over sand-dunes. When the

water in Lake Cochichewick subsided to its present level, the southern outlet, over the granite ridge, had become dammed up by till and the stream running from the lake was forced to turn northward, and cut its present channel through the drift-sand to the Merrimac river.

Johnson's pond and Chadwick's pond, in Groveland and Boxford, are similarly situated. The glacial drainage was easterly across South Groveland and the northern part of Georgetown, and sand and coarse gravel ridges cover the entire region. The tracks of the Haverhill and Georgetown electric railway are laid on a sand and gravel terrace, which in some parts of the area exhibits a remarkable kame topography. One especially good example is to be seen in the region known as "Federal City," where short kame-like ridges, alluvial cones and "kettle holes" are features of the landscape. Uptack hill, in Groveland and Boxford, a nearly bare ridge of Cambrian rocks, three miles in length, and having an elevation of two hundred and forty feet in Boxford, southeast of Johnson pond, cuts off the natural drainage to the southeast and forces the streams in this area northward to the Merrimac, through the fissile and softer slate and sandstone rocks. Chadwick's pond was probably a deeply sunken ice-block attached to the larger block that occupied the site of Johnson's pond. Its southeasterly drainage into Johnson's pond shows no special features of overwash or outwash gravels, but toward the northeast overwash gravels fill the valley between Dead hill in Groveland and a low drumlin to the north in Bradford. These overwashed gravels cover the boulder-till in low rolling surfaces and short ridges as if, in the glacial period, there had been a drainage from this pond into the Merrimac river, at Bradford. Little Niagara brook in Bradford follows this course.

The southern side of the Merrimac river from opposite Hale's island to Groveland bridge, shows a nearly continuous ice-contact with steep ridge-like banks of morainal clay and gravel capped by fine overwash sands which extend parallel to the river for a distance of about one mile, to Argilla brook, the outlet of Johnson's pond. The valley occupied by Argilla brook, was a drainage-crease in front of the glacial ice. From Bradford, the Merrimac flows in a southeasterly direction for about two miles to Argilla brook, and then bends and flows toward the northeast for about five miles. This bend in the river was a drainage course when the waning ice-sheet was less than two hundred feet in thickness, and it continued to be a general dumping-ground for glacial streams from the north, long after the ice had retreated beyond the northern limit of the state.

Fig. 161. — ICEBERG HOLE IN AN OUT-WASH SAND-PLAIN EAST OF WENHAM SWAMP.
Arbor street, Wenham.

Fig. 162. — ICEBERG HOLE ON THE EAST SIDE OF ARBOR STREET.
Wenham.

Fig. 163.—KAME TERRACE, MARKING AN ICE CONTACT ON THE SOUTHEASTERN SHORE OF LEACH'S SWAMP, AN ICE-BLOCK HOLE.
West Wenham.

Fig. 164.—ANOTHER VIEW OF THE ABOVE.

(See Fig. 171.) On the south side of the Merrimac, Hutchings' hill, in Groveland, and Brake hill and Farm hill, in West Newbury, show at their bases and up their sides to the one hundred foot contour lines, old beach shore-lines of clay, sand, and gravel. As these hills have an elevation of over two hundred feet, when the glacial ice-front had melted to a thickness of less than two hundred feet, its drainage would necessarily have been in the valleys between the hills and its deposits would have been dropped according to the size and weight of the material, the coarse sand and gravel near the river, fine sand next, and the clay beyond. This is precisely what is found in the area south and southeast of Groveland bridge. Kames of coarse gravel extend from the river to the railroad station, and are succeeded by sand stretching to Pine hill and appearing on both sides of the railroad track until the Georgetown boundary line is reached.

Cheney's hill, in Groveland, on the bank of the Merrimac, formerly was composed entirely of boulder-till. This was cut down nearly to the level of the river, and afterwards built up by overwash sand and gravel. The sand-plain extends toward the north and is now occupied by a cemetery, where Palmer's creek cuts down through the sand to boulder-till and clay at the level of the river. Round pond, Kenoza lake, and Lake Saltonstall, all in Haverhill, are sites of glacial ice-blocks and are surrounded by drumlins and overwash gravels on their southeastern shores. Overwash gravels form the sand-plain at "Riverside," and on both sides of Argilla brook extending up on Huckleberry hill and down to the Merrimac. River silts of Post-Pleistocene age form the banks of the river on the north (see Fig. 173), and on the south it has a tendency to cut down its bank as it flows by Bradford, Groveland, and West Newbury.

Creek pond, or Crystal lake, in North Haverhill, is situated in a rock-bound basin surrounded by micaceous granite. Creek brook, its outlet, flows southeasterly and was probably the drainage outlet from this pond when it was occupied by glacial ice. Outwash sands and gravels extend towards the south on both sides of the brook as far as West Meadow hill, and also to the base of Silver hill and to the banks of the Merrimac.

South of Uptack hill, the Parker river flows across Boxford and Georgetown to Rock pond, a distance of about three miles. The river valley is in a line parallel with the front of the glacial ice, and the usual overwash sand-ridges, cones, and kames which expand to sand-plains and rolling sandy terraces, are to be seen its entire length. On part of this area the exact line of contact has been cut away by Post-Pleistocene erosion.

The ice-front when it occupied this valley must have been over two hundred feet in thickness, for overwash gravels and moraines of boulders are found above the two hundred foot contour line on Stiles' hill and Spofford's hill in Boxford, and Bald Pate hill in Georgetown. Bald Pate hill is a typical drumlin in which a channel has been cut by a landslide and boulders from the boulder-till have been pushed forward and down its southeastern slope. This channel, or valley, caused by an ice advance, has since been filled by overwash gravels from the contact in the Parker River valley. During the final retreat of the ice-sheet from this region, overwash gravels extended across Boxford and into Topsfield.

A series of ponds in Boxford — Stiles', Spofford's, Perley's, Four Mile, and Cedar, are all ice-block holes showing contacts on their southeastern shores. Cedar Pond brook forms the Kimball mill-pond and, on the south side of the road below the pond, there is a deposit of infusorial earthy clay from one to three feet in thickness and covering about one acre which is, without doubt, of glacial age. Stevens' pond, in Boxford, is a typical ice-block hole where an elongated mass of ice extended from the large block in the valley of Four Mile pond. The steep southeastern shore of Stevens' pond is a fine example of contact, the gravel and clay covering nearly one hundred acres at the east of Stevens' hill, a low boulder-till ridge, and extending southerly on both sides of Pye brook as far as Topsfield. The surface of this plain is composed of fine quartz, sand and silt forming the soil of the area. Below the surface, from three to ten feet, the deposit is found to be clear of sand and composed of round gravel-stones three to six inches in diameter, each stone as smooth as if from a sea beach. Between Fish brook in Boxford, and Mile brook in Topsfield, an area two and one half miles long and two miles wide, the surface is marked by short ridges and circular terraces, "kettle holes," and reticulated kames. South of Fish brook, as it flows between Boxford and Topsfield, there is an ancient sea beach with sand-dunes and wind-blown sands underlaid by round gravels. These sea beach deposits of sand and gravel formerly extended from this point in a southeasterly direction to the present seashore, but were largely removed by wash of waters from melting ice-blocks.

Forest lake, in Middleton, is a basin in the granite gneiss rocks ploughed out by the advancing ice-sheet. The shore at the southeast of the lake exhibits no evidence that this basin was formerly occupied by an ice-block as there is no ice-contact. Bare ledges and water-washed boulders cover the area extending southerly across the Ipswich river to

Fig. 165. — WENHAM LAKE.
The tree-covered point at the left is a gravel terrace marking an ice contact.

Fig. 166. — DRAINAGE CREASE ABOVE A LAND-SLIDE ON THE SOUTHWESTERN SIDE OF HOG ISLAND.
Essex.

Fig. 167.—INLAND SAND-DUNES AT EAST GEORGETOWN NEAR THE BYFIELD MEETING-HOUSE.

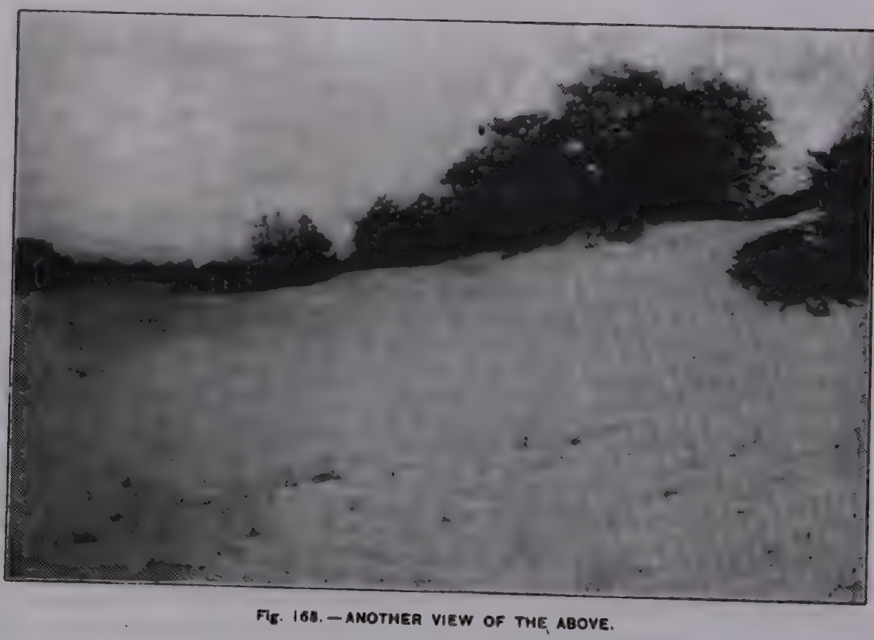


Fig. 168.—ANOTHER VIEW OF THE ABOVE.

Paper Mill hill. East of the lake, and near the bank of the Ipswich river, there is a narrow lagoon with grass-grown sand-dunes extending nearly to the dam at the paper mill — without doubt, in interglacial times, washed by the sea, in fact, an inland sea beach with its fringe of sand-dunes on the southeast.

The Ipswich River valley from North Reading to Danvers, shows evidence that it was submerged beneath the sea for a long period after the retreat of the glacial ice from this region. Northward, across North Reading, Wilmington, and Tewksbury, to Lowell, the evenly-bedded sands and gravels which cover the area extending towards Andover and the Merrimac river, furnish conclusive evidence of sea-laid deposits in a shallow basin of the ocean. Sand and gravel terraces across this area also mark the ancient sea beaches. Paper Mill hill and Upton's hill, both having an elevation of about two hundred feet, are steep-sided hills of fine sand, and probably mark ice-contacts from near their summits. Walden's hill, two miles to the south, having an elevation of one hundred and eighty feet, is composed of ordinary coarse gravel with numerous large boulders upon the surface, probably dropped from the bottom of floating ice, the sand and silt between having been removed by sea wave-action and washed towards West Peabody, where large deposits of sand and gravel are found.

Will's brook, in Lynnfield, occupies a valley in a swamp one third of a mile wide and one sixth of a mile long. This swamp was an ice-block hole, an extension south from the main mass of ice in the Ipswich river valley. Outwash gravel and sand from this valley formed Pine hill and covered the surface of the whole area of Lynnfield Centre. Pillings' pond and Suntaug lake are sites where ice-blocks were stranded or where remnants of local glaciers remained. The ice-contact on the southern and southeastern shores of Suntaug lake is a remarkably good example, having the steep slope of the sand and gravel sliding down to the shore of the lake. This contact formed a terrace with an elevation of forty feet above the surface of the lake, and spreading out as a sand-plain in a southeasterly direction for over a mile. North of the lake and near the corner of Lake street and the Newburyport turnpike, there is a ridge of granite boulders, in part resting on the hornblende granite ridge of the region, probably eroded *in situ*, which were pushed forward by the glacial ice, and deposited as a lateral moraine, marking a halting place of the glacier in its retreat northward. These boulders are identical in character with the granite of the Peabody and South Lynnfield

region, and no outcrop of similar granite is known in New England in the line of glaciation toward the northwest.

The peat swamps south of Phelps' mills indicate ice-block holes, and the region to the southeast is covered with short terrace-like ridges, kames which expand southward into sand-plains, and numerous "kettle holes" which are very intricate in outline. The sand-plain occupies the region known as the "Kingdom" and extends into West Peabody.

The series of crystalline ridges of diorite and granite rocks, south and southeast of Danvers, is interesting as showing that drift boulders from these outcropping ridges of bed-rock usually were merely pushed forward, for boulders of the diorite rock from Hog hill, Peabody, or from Danvers, rarely are found as erratics on the granite areas, whereas, on the diorite areas, the boulders are invariably diorite. That the diorite boulders are nearly always angular with sharp corners is another distinctive feature, whereas, the granite boulders, on the granite areas of Peabody and the Lynn woods are usually from subangular to well-rounded blocks. Indeed, concerning the boulders in these areas, the rule is so distinctive that with few exceptions, the boulders on the surface indicate the bed-rock beneath. Occasionally erratics are found, however, brought from a distance. Boulders from the Topsfield red granite and the Boxford foliated quartz diorite are occasionally seen on the backs of drumlins, and in the lower areas of boulder-till or hard-pan in the valleys of the diorite areas, and an occasional boulder of the typical hornblende granite from the Peabody area is sometimes found perched upon the summit of the diorite areas in the southeastern part of Peabody, in Salem, and on the sea-shore at Marblehead. The ridges of granite boulders on the granite areas in Peabody and in the Lynn woods, are usually found to be accumulations of these erratic boulders resting on the sides of valleys, and probably a large part of them are boulders of erosion that have been carried forward toward the southeast a short distance.

Ship rock, a large hornblende granite boulder in Peabody, the property of the Essex Institute, and estimated to weigh about twenty-two hundred tons, is perched upon a ledge at an elevation of about one hundred feet above mean sea-level. (See Fig. 174.) Across the valley, two-thirds of a mile distant, in a northwesterly direction, which is the direction of glaciation for this area, there is a hornblende granite outcropping ledge with an elevation of two hundred and thirty feet above mean sea-level. Without doubt "Ship Rock" was formerly a part of this outcrop,

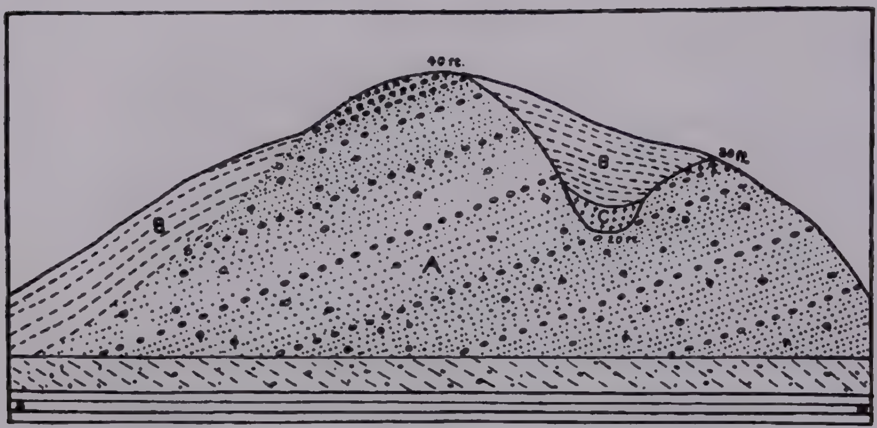


Fig. 169.—CROSS-SECTION OF A TERRACE AT HIGH STREET, NEWBURYPORT.
A. Sand and gravel. B. Clay with sand partings. C. Peat deposit.

Fig. 170.—GLACIAL GROOVE IN A QUARTZ DIORITE LEDGE ON THE EAST SIDE OF GREEN STREET. Newbury.

Fig. 171.—MERRIMAC RIVER.
The bend below Mitchell's falls, showing deposits of river silts. Kame gravels in the foreground.

Fig. 172.—ENCLOSED BLOCK OF FERRUGINOUS GRAVEL PROBABLY DEPOSITED IN A FROZEN MASS DURING LATE GLACIAL TIMES.
Sand-plain east of the railroad station at Hampton, N. H.

Fig. 173.—MERRIMAC RIVER AT MITCHELL'S FALLS.
Lone Tree hill, Methuen, in the distance.

Fig. 174.—SHIP ROCK, PEABODY.
An erratic boulder of hornblende granite.

and was pushed forward by the glacial ice, or rafted across the valley attached to the base of a large berg, and becoming stranded, was left where it rests to-day.

There are many smaller perched boulders on this granite area (see Fig. 175) and also examples of boulders of erosion *in situ*, in all forms, from large granite blocks where the erosion has attacked the joint-plains of the massive ledges (see Figs. 176, 177) to blocks that have been eroded on all sides and are now simply boulders. The absence of soil, sand, and gravel, from about many of these ridges of boulders, gives a free access to the air under and around each block, and thus preserves it from decay. The drift on this area is very scant, and is usually boulder-till covered with disintegrated granite rock. In some places the disintegrated granite deposit is ten feet in thickness over the boulder-till covering the bed-rock. In areas where granite ledges are exposed to view, the northwestern side of the outcrop usually is ground down to a rounded surface, even when the face of the ledge is nearly vertical. (See Figs. 176, 177.)

Disintegrated granite is, without doubt, the result of glacial action. In North Beverly, on Dodge street, granite is decomposed to a depth varying from eight to twenty feet. The iron in the hornblende and free magnetite is leached out, the feldspars are kaolinized, and this liberates the quartz grains and thus the granite is disintegrated. This is the result of water-action, and as the disintegration of these granites is always on high lands, it is fair to presume that the water-action which leached out the iron-bearing minerals was the result of the melting of ice covering this region during the Glacial period.

A series of ice-block holes occur at Lynn — Cedar, Sluce, Flax, and Glenmere ponds — and immediately at the north are Brown's and Spring ponds in the town of Peabody. Small outwash sand-plains occur south and southeast from all these ponds in the form of over and outwash deposits. A subsidence of the land surface formerly covered this area with a sea of comparatively shallow depth, and its waters stripped the hillsides of their debris of soil, sand, and gravel, and left the outcropping ledges bare save for the boulders stranded upon their summits, while the valleys and sides of the hills were covered with boulders rounded by glaciation. Breed's and Holder's ponds in West Lynn, are rock basins, and the head-waters of small drainage streams which, flowing towards the south between Walnut and Blakely streets, West Lynn, have cut their channels through the thin coating of sand, and now flow over the fossiliferous beds of glacial marine clay.

Lake Quannapowitt, in Wakefield, is the site of a large mass of glacial ice, and is surrounded by overwash gravels, alluvial cones, terraces, kames, and sand-plains. The ice-contact on the southeastern shore of the lake is very marked, and extends southeasterly across the town. The material is coarse gravel capped by fine sand. This sand, together with other deposits, followed the ancient glacial drainage-stream, now the Saugus river, in its south-southeasterly course, and supplied the sands and fine gravels which now cover Saugus and extend to the sea. The streams flowing through the valleys between the ancient volcanic rocks and over the remnants of the Cambrian sediments in North Saugus, carried these sediments and blocks of Cambrian conglomerates across Lynn harbor, and in time deposited a considerable amount upon Nahant. Erratic boulders of quartzite conglomerate and volcanic breccia from Castle hill and Breakheart hill, in Saugus, are often found on the Lynn harbor side of Nahant.

The area about Saugus and Lynn is deeply glaciated. Grooves and scratches are to be seen on the surfaces of all outcropping ledges, and always run in a northwesterly to southeasterly direction. Boulder-till is found in varying depths in all parts of the region where excavations have been made for gravel. This boulder-till forms a covering over the bed-rock, and is usually composed of local materials — quartz diorite granite, and angular fragments of the ancient volcanic rocks, mixed with sand, gravel, and clay — a typical boulder-till with no form of stratification.

Cape Ann, from Beverly to Rockport, is an area of intense glaciation and post-glacial erosion. The surfaces of all outcropping ledges of hornblende granite and syenite have been rounded and smoothed on the sides and summits and then stripped of débris by sea-action. (See Fig. 178.) Niles' pond on Eastern point, westerly from Brace's cove, is a shallow, glacial basin, having a barrier just above sea-level in Brace's cove, over which extremely high seas often break. (See Fig. 179.) This pond at some earlier time probably was a lagoon, back of the barrier which might be called a tombola. Several good examples of augite syenite (akerite) glacial erratic boulders are found perched upon hornblende granite outcropping ledges in the area known as Beverly common pastures, on the southeastern part of Bald hill. The syenite appears by the side of the road, and at the northeast, about one mile and a half distant, a large boulder of syenite, known as "bung-stopper rock," is perched upon a granite ledge. Several large square boulders of granite are found on the augite syenite area of Bald hill. Probably they are erratics from Wen-

Fig. 175.—HORNBLENDE GRANITE BOULDER.
Perched upon boulders eroded *in situ*, Peabody.

Fig. 176.—HORNBLENDE GRANITE BOULDERS ERODED *IN SITU*.
Peabody.

Fig. 177.—HORNBLENDE GRANITE LEDGE AT PEABODY, SHOWING HORIZONTAL JOINTING.

Fig. 178.—SYENITE LEDGE ROUNDED BY THE ACTION OF GLACIAL ICE.
East Gloucester.

Fig. 179.—NILES' POND, EASTERN POINT.
Gloucester.

Fig. 180.—HARD-PACKED BOULDERY GRAVEL COVERED BY A MORAINE OF BOULDERS.
Gloucester.

ham or Hamilton. Under these boulders, where the surface of the ledge has been protected from the weather, it is usually glaciated by scratches and fine striations.

Squam river, in Pre-Glacial times, was a small stream draining the region of Gloucester, West Gloucester, and Rockport. During the Glacial period its channel was broadened and cut down to a considerable depth by the advancing ice, which also formed Gloucester harbor. The deep channel that was formed in Squam inlet has since been filled with detrital material brought in by the sea. In 1643 a cut or canal was dug, connecting Gloucester harbor with Squam inlet, and thereby Rockport and a part of Gloucester became an island at high tide. From the appearance of the shore on either side of the cut, the early excavations above the sea beach were made through boulder-till, deposited there under the glacial ice. Severe storms have at times filled this cut with sand and gravel. In 1829 it was deepened and enlarged by the Gloucester Canal Company, and since then the tide has ebbed and flowed through the canal without interruption. The drainage area occupied by the inlet was formed at a contact of the hornblende granite and a massive syenite rock — nordmarkite. Probably much iron was at that time formed, and upon oxidation was easily removed by stream-action, thus defining the bed of the ancient drainage stream. Nordmarkite has been previously mentioned as granophyric granite. It is a form of augite syenite.

During Inter-Glacial times the entire coast-line of Essex County, without doubt, was quite different in outline from that of to-day. The islands which fringe the mainland were formerly its outer edge. The inner harbor at Gloucester was then dry land, and Eastern point was connected with "Norman's Woe," a small stream flowing into the outer harbor from Squam river, alone separating the points. Towards the northeast, Eastern point was connected with Salt, Milk, and Thatcher's islands, and Londoner rock off Rockport. The bed-rock of the mainland and of the skirting islands is of the same formation. From a study of the action of the sea in cutting back the cliffs and headlands, it is safe to assume that the waves, aided by an advancing glacier, might have scoured out the present harbors and removed all the land forms within several miles of the coast-line in the space of a very few thousand years.

The present drainage system of this area seems to be the same as in Pre-Glacial times. The streams flow northerly and northeasterly in the valleys occupied by them before the Glacial period. The glacial drainage and the glacier itself flowed in the opposite direction. In a few instances

where soft rocks occurred, the glacial streams were enabled to cut down their beds and capture the stream, and thus have been preserved to the present time. The Saugus river, from Wakefield to the sea, is an example, and the various inlets or drowned stream-valleys flowing into Salem harbor from Danvers are other excellent examples.

Nearly the entire surface covering the bed-rock of Gloucester and Rockport is boulder-till capped with hard-packed bouldery gravel in varying thickness. (See Fig. 180.) The latter was probably deposited from material incorporated in the base of the glacial ice, which, upon melting, left these bouldery gravels. This gravel may be seen in roadside cuttings and in gravel-pits. The materials from which it is composed are heterogeneously mixed together without the slightest indication of stratification. Thus, in form, it is like boulder-till, yet unlike it, for little or no clay is mixed with the boulders and gravel. Dogtown Common, at Gloucester, was in front or at the east of the boulder-belt. It is covered by a low, rolling ridge, apparently a kame-plain of sandy gravel. Upon this area many of the early settlers built their houses, and numerous cellar-holes, fenced fields and pastures are yet to be seen. (See Figs. 181, 182.) This kame-plain indicates that subglacial stream drainage deposited the sand and gravel on the surface of the boulder-till. The serpent kame or osar, near the Rockport railroad station, is also a deposit of sand and gravel marking the course of a subglacial stream that flowed under the glacial ice-cap on the surface of boulder-till. Pigeon hill, southwest of Pigeon Cove harbor, is a typical drumlin of boulder-till. In this till are found boulders and pebbles of the hornblende granite of the region; granite gneiss from Boxford and Andoover; porphyritic granite from Amesbury; a coarse feldspar granite, probably from Jackmantown, Maine; and felsite and diorite from Rowley.

A moraine of boulders near the Beach Grove cemetery at Rockport forms for nearly three hundred yards an irregular wall some fifty feet in width. (See Figs. 183, 184.) These boulders are nearly all of large size, some of them weighing one or two tons each. They are in rounded to subangular form, and become a striking feature in the landscape as they are deposited upon high ground. This moraine marks a halting-place of the great continental ice-sheet in its retreat northward at the close of the Glacial period. It follows the slope of the hill, and at a point about two hundred yards southeast of Beach Grove cemetery, it occupies a drainage-crease in the bottom of a steep-sided valley, where the boulders are piled in great profusion and crop out from beneath the present surface.

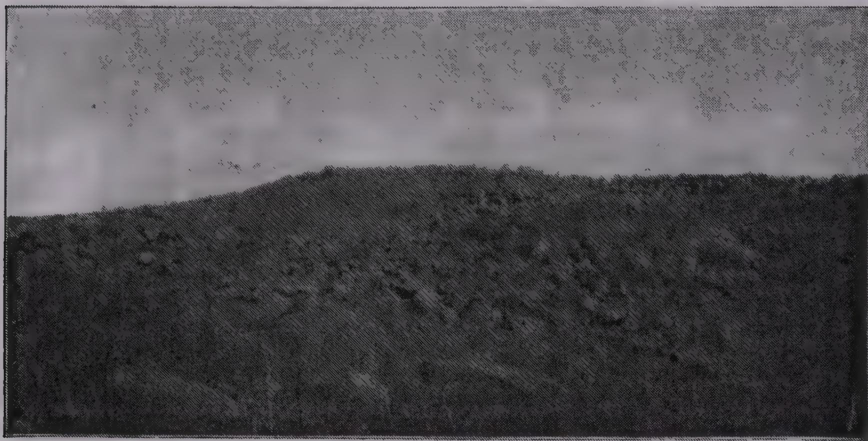


Fig. 181.—MORAINES OF BOULDERS AT ROCKPORT.
Showing a halting place of the glacial ice, northeast of Dogtown common, during its retreat from the region.

Fig. 182.—GLACIAL ERRATIC BOULDERS AT DOGTOWN COMMON.
Gloucester. The walled areas formerly were cultivated.

Fig 183.—MORAINES OF BOULDERS, EAST OF BEACH GROVE CEMETERY, ROCKPORT.

Fig. 184.—ANOTHER VIEW OF THE ABOVE

Fig. 185.—WOLF HILL, GLOUCESTER.
Perched glacial boulders upon its summit.

Fig. 186.—DRAINAGE CREASE AT MANCHESTER.
The outlet from a large valley at the west which was filled with glacial ice.

From the valley the moraine extends to the swamp at the northern end of Cape pond, where it expands, and the boulders are scattered in an irregular line reaching to the sea-shore near East Gloucester.

Glacial erratic boulders and blocks of granite are scattered over the whole surface of Essex County, but at Gloucester and Rockport such boulders are found on the summits of the high lands, and also are perched upon many of the granite ledges, which still retain glacial grooves and scratches under the protecting boulders. (See Fig. 185.) These glacial scratches and striæ have a northwesterly to southeasterly direction, sometimes with a slight variation to the east, and indicate that these erratic boulders and blocks of granite, especially those on the high land of Dogtown Common, have been transported here from higher elevations towards the northwest, probably from Annisquam or West Gloucester.

At Manchester, north of Summer street, the entire area extending to Long hill is covered by a series of short terraces and sand-plain deposits. In the Essex and Manchester woods, the great swamp that extends from Millstone hill shows on its southeasterly shore a series of terraces that were formed when the swamp was a lake of considerable extent. These terraces are the result of changes of water-level in the lake, as the shore does not indicate an ice-contact, and no outwash or overwash gravels are to be found in front of the terraces; in fact, the whole surface of the area towards the east and southeast is washed clean of débris except in a few deep pockets between the outcropping ledges. On the Essex river, between Chebacco lake and the village of Essex, there are terraces and stream-cuttings through the clay, sand, and gravel. In the boulder-till, at the base of Perkins' and White's hills, steep terraces of sand and gravel are to be seen in the valley through which the railroad passes. Probably stream-cutting has produced the numerous terraces which extend to the tidal marsh. Terraces, sand-plains, and moraines of boulders cover the surface of South Essex and West Gloucester, and extend to Long hill and the magnolia swamp at the base of Mount Ann. This swamp, which reaches for over a mile towards the southwest, was formerly an ice-block hole, but is now entirely filled with peat and covered by forest growth. Outwash gravels and their deposits of sand also fill the valleys between Mussel point and Kettle cove at Manchester. East of the railroad station at Magnolia is a remarkable moraine of boulders occupying a drainage-crease or valley by the roadside, and having in front an outwash sand-plain. (See Fig. 186.)

Ice-block holes occur in Rockport although Cape pond was probably

formed by moving ice. At the southern and southeastern end of the pond, the drift is seen in short ridges of gravel in the valleys between the granite out-crops (see Fig. 187), and northeasterly from the pond there is a peat swamp which was undoubtedly the site of an ice-block. Northwesterly from the pond there is another peat swamp, which was an ice-block hole, having a contact towards the south with gravels extending around Railcut hill to Long beach.

The most striking feature of the glaciation of Gloucester and Rockport is the boulders which cover the surface. Many of these are boulders of erosion *in situ*, which are continually creeping down the steep hillsides to accumulate in the valleys. There are also moraines of boulders piled in windrows, large erratic blocks resting upon boulder-till, and boulders perched upon the glaciated surfaces of outcropping granite ledges.

The Raccoon rocks in the Essex and Manchester woods is an outcropping granite ledge, whose northwestern face has been broken down by the action of the frost. (See Fig. 77.) The entire face of the ledge, from the great swamp to Wyman's hill in Manchester, is a crumbling mass of angular fragments. Large masses of the rock are forced outward nearly every winter by the action of water freezing in the cracks and crevices, the débris falling into the swamp below. In 1887, a large cave existed in this ledge, the mouth of which, a few years later, was covered by a large fragment of rock weighing several tons, which had fallen from the face of the ledge above.

Moses' mountain, Manchester, is a massive outcrop of hornblende granite, the entire surface of which is well rounded and smoothed by glacial ice. Sunset rock, or the Agassiz boulder, is a large mass of granite perched upon a granite ledge beside the road leading from Manchester to Essex; and in the swamp north of this boulder there is a series of large, erratic boulders, one of which is the largest boulder in Essex County. It is a rounded mass of syenite akerite, thirty-two feet in height above the surface of the swamp. It is thirty-five feet wide and forty feet long, and is estimated to contain 44,800 cubic feet of granite weighing 3,763 tons. A white pine tree, *Pinus strobus*, is growing on the top of this boulder, its roots extending into a crack or joint-plain. (See Fig. 80.)

Drumlins Carved by Landslides. — During the spring months, the surfaces of drumlins whose slopes are steep, become saturated with water from melting snow and rain, and certain areas of the upper-till frequently slip down on a more clayey and compact part of the till beneath, result-

Fig. 187.—CAPE POND, ROCKPORT.

Fig. 188.—INCIPIENT LANDSLIDE ON BRAKE HILL, WEST NEWBURY.

Fig. 189.—MATURE LANDSLIDE ON LONG HILL, WEST NEWBURY.

Fig. 190.—ANOTHER VIEW OF THE ABOVE.

Fig. 191.—ADOLESCENT LANDSLIDE, HOG ISLAND, ESSEX.
The slide has formed a bench near the fifty-foot contour line from which spring-water continually flows down the hill.

Fig. 192.—NORTH RIDGE, JEFFREY'S NECK, IPSWICH, AS SEEN FROM EAGLE ISLAND.
Showing a live landslide around the base of the ridge and above, a grass-grown bench of an earlier slide.

ing in an incipient landslide or washout. (See Fig. 188.) As the washout becomes more powerful, the scarp creeps up the hill, and widens, and each season water continues to issue from the starting-point on the hillside. This point is indicated in the illustration by the man standing. This flow of water continues to undermine the till, and large masses are washed down, to form a delta at the base of the hill. An excellent example of a mature landslide may be seen on the northern side of Long hill in West Newbury. (See Figs. 189, 190.) Here the whole slope of the hill is gradually sliding down and forming a false scarp which is over five hundred yards long and forty feet in its maximum height. During the spring, and also in other wet seasons, water in considerable volume issues from fifteen or more places on the face of this scarp, and undermines large masses of the till, which gradually slide down the surface of the slope, removing at the same time growths of trees, bushes, and grass, some of which afterwards take root where they are finally deposited. In Figs. 189 and 190, large trees of pine, elm, cherry, and apple are to be seen growing at the base of the scarp. The gravel, sand, and clay resulting from this landslide spread out and form a delta on the fields at the base of the hill, while much of the clayey sediment washes down the stream formed below the hill, and flows into the Merrimac river.

Examples of landslides on the surfaces of drumlins are to be found in many parts of the County, some of which exhibit a complete cycle from the incipient stage to the adolescent and mature. The latter is to be seen when the gradient on the face of the hill has so far leveled its slope that grass and bushes cover the surface and all that remains to record the landslide is the bouldery grass-grown scarp with a sluggish spring issuing from the base of the hill. (See Fig. 191.)

North ridge, a massive drumlin forming the northern part of Great Neck, Ipswich, has two landslides on its northwestern slope opposite Eagle hill. (See Fig. 192.) The northern slope of this hill exhibits a series of landslides in various stages of development, from the incipient to the adolescent and mature. On one part of the hill a number of benches have been formed, all of which are more or less grass-grown. Near the summit of the highest bench is a perpendicular scarp from two to ten feet high, the base of which slips down a little each season, and undoubtedly in time will slip into Plum island sound. Another example of an adolescent landslide may be seen on the northeastern slope of Stage hill, opposite Little Neck, Ipswich. A deep gulch or crease filled with

boulders and a series of springs at the base of the hill, together with a grass grown scarp reaching to the top, indicate where the landslide occurred.

Brown's hill, Hamilton, a round hill of very compact boulder-till, also shows an adolescent landslide where the graded grass-grown scarp slopes down to a ravine on the northwestern part of the hill, in which are a number of steep-sided water-holes, and below them a swampy area. Sagamore hill, Essex, a long, rambling drumlin, shows unmistakable evidence that a landslide has carved its surface. Graded slopes reach downward from the summit of the hill nearly to its base, where a number of springs and water-holes break out in the springtime and also in very wet seasons. If the slope from the valley were more abrupt, the steep-sided water-holes thus formed would cause a new landslide.

Ox pasture hill, Rowley, presents an excellent example of an adolescent landslide. On its western slope, at an elevation of one hundred feet, is a well-defined bench, and a number of feet higher there is another. These benches were caused by landslides, in which large masses of the surface of the hill have slid downward towards its base. Both benches are well-defined, as are the grass-grown scarps. A ravine, well up the hillside, in which the stream still flows from the face of the scarp, is covered with forest trees. Hunslow hill at Chaplinville, in Rowley, has evidence of an adolescent landslide on the northeastern part of the hill at an elevation of two hundred and fifty feet. The face of the hill has been cut down from near the summit, leaving a grass-grown scarp nearly one thousand yards in length with a maximum height of one hundred and fifty feet. A bench has been formed that is now covered with a growth of bushes and forest trees. Another example of a landslide may be seen on the northern side of Kimball's hill, East Haverhill, where the scarp has formed a half-circle or ox-bow, as the water flowing from the base of the hill has undermined the till and cut a channel through a small valley in the old scarp. Crowninshield's hill, a drumlin in the southern part of Topsfield, shows a steep, adolescent landslide, the sand and gravel from the wash of the slide forming a large sand-plain and ridge towards the southeast in Blindhole swamp. The landslide divides the hill into two parts, over which the Newburyport and Boston turnpike crosses where the ravine runs nearly east and west. Beyond the road, towards the west, the scarp and ravine wind southwesterly. The water-hole where the landslide first started may yet be seen in the eastern side of the hill, and following up the ravine a series of these water-holes also occur at intervals.

Fig. 193.—PLAN OF THE VALLEY OF PORTER'S RIVER, EAST DANVERS.
* Old Clay-pits.
* 1 Leda-clay. Edward Carr clay-pit.
* 2 Leda-clay. Peabody Pottery clay-pit.
T. Boulder-till.

Fig. 194.—CLAY-BEDS COVERED BY A THIN COATING OF RIVER SILT AND SAND.
West side of the Merrimac river near Mitchell's falls, Haverhill.

Fig. 195.—DANVERSPORT, SHOWING THE AREA COVERED BY BRICK-CLAYS.
Folly hill in the distance.

CHAPTER XI

CLAYS

In Essex County was the beginning of brickmaking and the earthen-ware industries of New England. Over two hundred years ago it was famous for its manufactures from clay. Clay-beds have been worked for brickmaking in nearly every town and village in the County, and Newburyport, Beverly, Peabody, and Danvers still continue the production of earthen-ware. At the present time bricks are made in twelve different cities and towns in the County.

Residual Clays, formed from the decomposition of ledge rock *in situ* are rare in Essex County. One bed, which was probably decomposed from a ledge of felsite, occurs on the west side of Kent's island, Newbury, and is now a very fine white kaolin. The deposit has not been worked and its extent is unknown. A mug made from this clay at the Beverly Pottery burned out white. Another mass of residual clay occurs in South Lawrence, and is the result of the decomposition of a ledge of gneissic granite, quartz being absent.

Upper Clays, used for bricks and pottery, were without doubt laid down in fresh water, for it is well-known among workers in pottery clay that the flooding of sea-water upon the surface of a clay-pit renders the deposit unfit for use. Such clay when baked in the kiln will not retain a glaze for it will slip from the surface. These upper clays are of varying thickness in different beds. In a brick-clay pit at Danversport, owned by Edwin Day, the clay is eighteen feet deep below the tidal-marsh on the banks of Waters' river. Without doubt this is an upper clay, for no fossils have been found, or evidences of any kind that might connect it with the marine or leda-clays. The upper clays on the bank of Crane river in Danvers, are twelve or more feet in thickness. They are covered by a bank of sandy gravel some fifteen feet in depth, and rest upon a parting of water-worn gravels six inches in thickness, beneath which the blue to black leda-clays are deposited which are below the level of the sea. The brick-clay in Edward Carr's pit near Liberty street, Danvers, is capped with about one foot of soil and sandy gravel,

beneath which the clay is found to vary from eight to twelve feet in thickness, and is interrupted every few inches by a parting of fine sand. (See Fig. 193.)

At Haverhill, the brick-clays usually rise to the surface and are of unknown depth. (See Fig. 194.) One pit near the Haverhill and Groveland bridge has been excavated to a depth of thirty feet below the surface. The clay is of a reddish-gray color, and is composed of fine mud with no gravel or sand partings. Boulders and pebbles are rarely found. It is easily worked and may be drawn upon a potter's wheel into very long, thin ware, and takes a fine glaze. The clay found at Newburyport is of the same reddish-gray color as the last, but it contains numerous partings of sand, some of which are six feet in depth. A well driven to the depth of one hundred and eighty feet did not pass through the deposits. The brick-clays at Ipswich are found in low-lying tracts of land not more than six feet above the surface of the meadow. The clay-beds are from eight to ten feet below the surface, and at the present time are so much below the drainage level of the area that they are not worked. The clays found at Beverly are all below mean sea-level, but are of superior quality for making pottery. Salem clay deposits, a number of years ago, were excavated to a point below the drainage level of the region, and the industry of brick- and pottery-making therefore ceased to be profitable.

Four ounces of clay from the brick-clay pit of Edward Carr, Liberty street, Danvers, when washed, gave one ounce of fine sand, the residue being silty mud, which in ten hours' time settled to the bottom of a jar of water, leaving the water clear. The color of this clay is reddish-gray, and a sample taken seven feet below the surface, under microscopical examination, was found to be composed of grains of feldspar, quartz, mica-plates, epidote, chlorite, and a flocculent mass of chlorite and kaolin.

Manufactures of Clay. — Common bricks, to the number of 13,535,000, are made annually in Essex County. Danvers and Lynn produce 4,000,000 pressed-bricks, and 1,800,000 feet of fire-proofing is made from clay by the New England Fire proof Manufacturing Company of Newburyport. The Beverly Pottery (Estate of Charles A. Lawrence) manufactures 183,500 pieces of earthen-ware annually, and the Peabody Pottery Company (Moses B. Paige) produces about the same number. These two potteries use about six hundred tons of clay each year. The Nickerson Pottery Company of Newburyport manufactures fine ware from residual clays brought from Ohio, mixed with Newburyport clay, hematite, etc. The Danvers

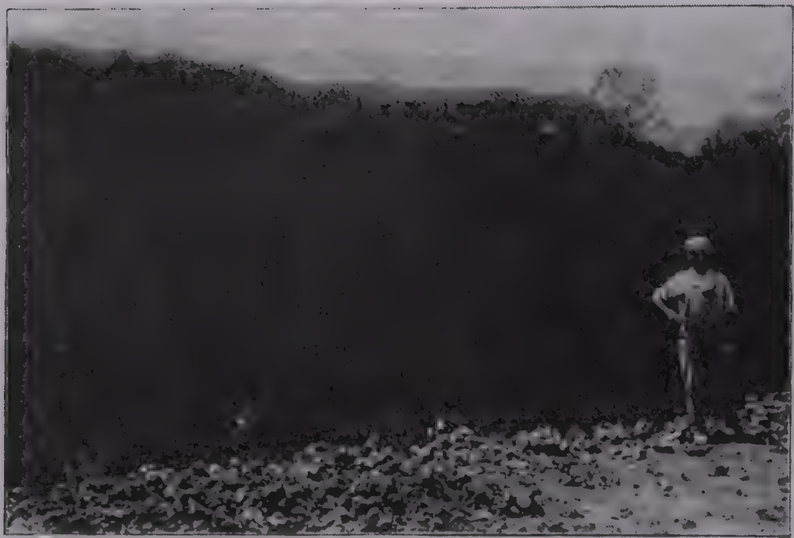


Fig. 196.—LEDA-CLAY IN BOTTOM OF EDWARD CARR CLAY-PIT.
Liberty street, Danversport. Location of fossils is indicated by dots.

Fig. 197.—PEABODY POTTERY COMPANY'S CLAY-PIT NEAR PURCHASE STREET,
Danvers. Location of *Portlandia Arctica* fossils is indicated by dots.

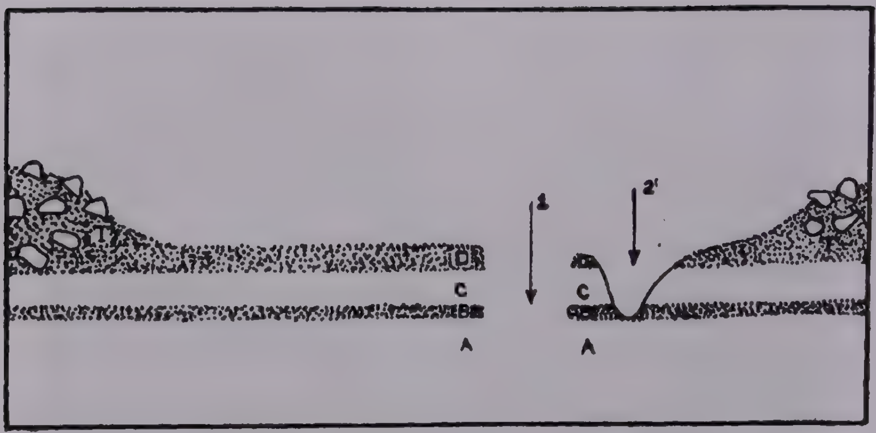


Fig. 198.—CROSS-SECTION OF THE VALLEY OF CRANE RIVER, DANVERS.
1. Peabody Pottery Company's clay-pit. 2. Crane river.
A. Leda-clay. B. Sandy gravel. C. Brick-clay. T. Boulder-till. D. Sand and soil.

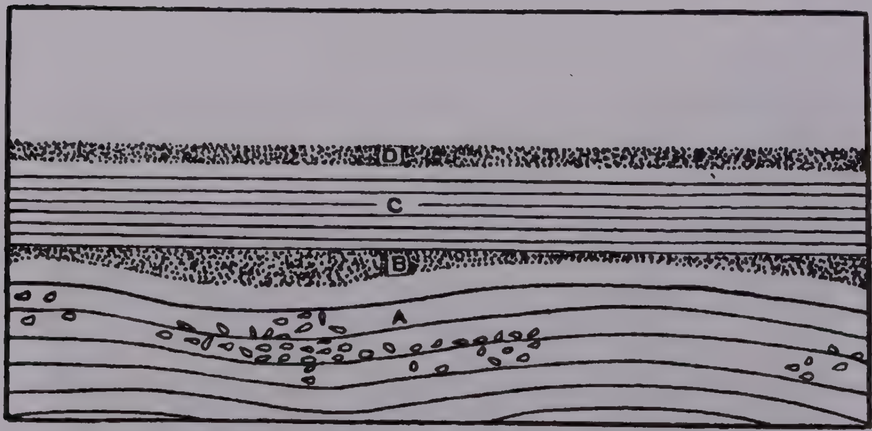


Fig. 199.—CROSS-SECTION OF THE CLAY-PIT OF THE PEABODY POTTERY COMPANY.
Near Purchase street, Danvers.
A. Leda-clay, showing position of fossils of *Portlandia Arctica*. B. Sandy gravel.
C. Reddish-gray brick-clay. D. Sand and soil.

clays are also used at the cast steel forge works in Lynn, five hundred tons from the leda-clay pit on Liberty street being used annually (1904).

Glacial Marine or Leda-Clays. In Essex County these clays are composed of fine mud, silt, and sand deposited by the waters melting from glacial ice in front of the land ice, and probably situated in bays and estuaries formerly existing along the coast.

The depth of these deposits with few exceptions is unknown. In the clay-pit on Liberty street in Danvers, a boring was made to the depth of forty feet without passing through the clay. On Bridge street in Salem, the gas company drove a well through seventy-two feet of clay before reaching gravel and a good supply of water.

The leda-clay, so far as examined, contains fossils only locally. In the Carr clay-pit, Danvers, the fossils first collected were found in the extreme southern portion of the pit, the deposit extending into the face of the bank about eight feet. As the clay was removed from this bank, the author collected many perfect shells and hundreds of fragments. Not long after, at a point about one hundred feet northeasterly from the first bed of fossils, another bed was uncovered, and for a space of ten feet, in a slight dip in the clay, *Portlandia Arctica* occurred. The larger number of fossils were collected in deeper holes opened in the bottom of the pit, although many of the openings made were entirely barren of results. The men who are working the clay rarely notice the fossil shells, or, if they do, the fact is concealed from a fear that the fossils may injure the reputation of the clay for brickmaking.

The upper brick-clays contain numerous pebbles and small boulders, which seldom weigh more than one hundred pounds, and which are usually well-rounded pieces of hornblende granite or diorite — local bed-rock from the region. Sand and gravel partings are found, indicating seasons of swiftly flowing water when the boulders might have been transported, especially if partially buoyed up by ice. The leda glacial marine clays contain only a few small pebbles, seldom weighing over two pounds each, and with an occasional small pebble of granitic gneiss.

Fossil shells were first discovered by the author in April, 1902, in a clay-pit opened by the Peabody Pottery on the bank of Crane river, Danvers, a small tidal-stream. (See Fig. 197.) This river has cut its bed through a bank of sandy gravel some fifteen feet in thickness. Under the gravel is a deposit of reddish-gray pottery- or brick-clay, twelve or more feet in thickness, below which is thin parting of coarse gravel about eight inches deep, and below this a blue to black clay of unknown depth,

the surface of which is below mean sea-level. This blue clay contains thousands of fossil shells, which occupy an undulating series of lines, from a few inches to two feet wide, across the side of the pit, and running in a northwesterly to southeasterly direction. The clay is bedded, and the dip of the beds is very marked, being about 25° southwest. Upon splitting the clay along the bedding planes, numerous fossil shells were exposed to view (see Figs. 198, 199), which proved to be *Portlandia Arctica*, Gray, all being small in size, none measuring over 8 mm. long by 6 mm. wide. No other species of fossil shells were found. This was the first time that this fossil shell had been found in the clays of Massachusetts.

The most important deposit, as regards the number of species of fossils, was found in Edward Carr's clay-pit on Liberty street, Danvers. The clay was from eight to fifteen feet in thickness, and was covered by one or two feet of soil and sandy gravel. (See Fig. 196.) Several hundred fossil shells were collected in the bottom of this pit, comprising twelve species of mollusks, three species of *Bryozoa*, and several species of *Foraminifera*. The marks in Fig. 196 across the base of the clay, near the blade of the shovel and behind the man in the photograph, indicate the horizon where the fossils occur. (See Figs. 200, 201.) A brick-clay pit in Lynn, owned by Richard Graham, is covered by a cap of sand and gravel varying from six to ten feet in depth, below which is a bed of reddish-gray brick-clay eight feet in thickness. Below this clay is found blue clay, having partings of fine sand every few inches, and containing numerous fossil shells of *Portlandia Arctica*. A foot below the bottom of the pit the shells of *Saxicava Arctica* were found in considerable number. The surface of the soil above this pit is about twenty feet above mean sea-level. Birch Pond brook runs over the clay-beds within a few feet of this pit. The finding of fossils in this leda-clay establishes an horizon of glacial marine clays in the area known as the Boston basin. This leda-clay is of a deep bluish-gray color when moist, but when dry it becomes a light gray. Half an ounce of fine quartz sand was obtained from eight ounces of this clay when washed and placed in a sieve, ninety mesh to an inch. The residue, a fine silty mud, when well shaken in a jar of water, settled to the bottom in fifteen hours, leaving the water clear. A microscopical examination proved this clay to be composed of grains of quartz, feldspar, epidote, calcite, a few small plates of mica, some tourmaline and garnet sand, masses of chlorite and kaolinized feldspars, several shells of species of *Foraminifera*, spicules of sponges, spines of echini, and some diatoms.

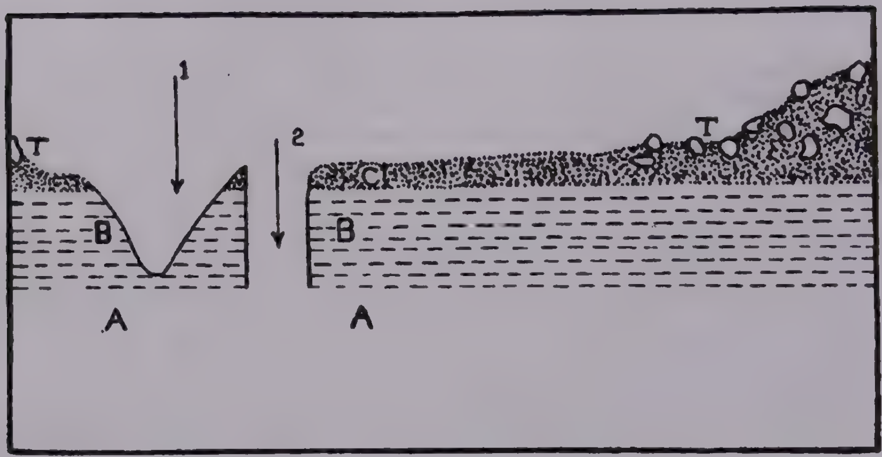


Fig. 200.—CROSS-SECTION OF THE VALLEY OF PORTER'S RIVER, DANVERS.
1. Porter's river. 2. Edward Carr clay-pit.
A. Leda-clay. B. Reddish-gray brick-clay, with sand partings. C. Sand and soil. T. Boulder-till.

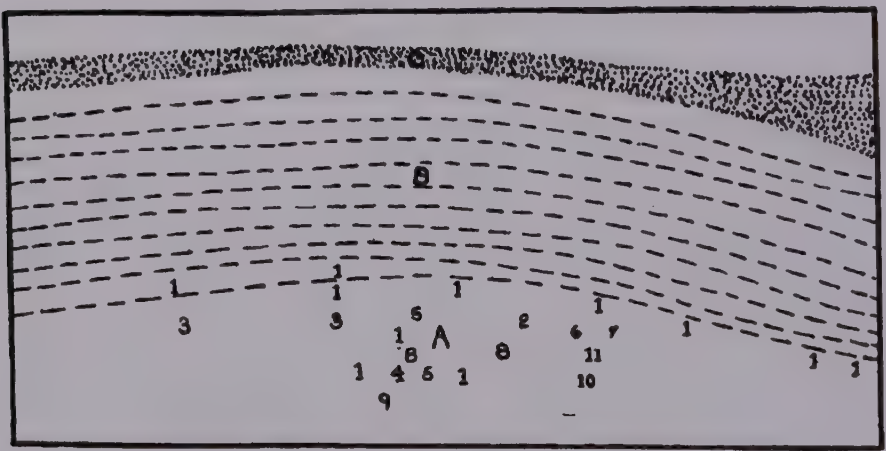


Fig. 201.—CROSS-SECTION OF THE EDWARD CARR CLAY-PIT.
Liberty street, Danvers.
A. Leda-clay. B. Brick-clay with sand partings. C. Sand and soil.

1. ***Portlandia Arctica***, Gray.
2. ***Pandora glacialis Gouldiana***, Dall.
3. ***Lyonsia arenosa***, Mörch.
4. ***Thracia myopsis?***
5. ***Portlandia lucida***, Loven.
6. ***Saxicava Arctica***, Loven.
7. ***Schizoporella hyalina***, Linn.
8. ***Schizoporella hyalina***, var. ***Danversi***, Sears.
9. ***Macoma Baltica***, Linn.
10. ***Modiolaria discors***, Loven.
11. ***Modiolaria laevigata***, Gray.

Fig. 202.—FOSSIL STARFISH, *ASTERICANTHIAN LINCKII*, MULLER.
Found in the Richard Graham clay-pit, Lynn. In the photograph the fossils are resting in a tray measuring 18 1-2 by 21 1-2 inches.

The leda-clay contains, in certain areas, numerous clay-stones or clay concretions, many of which have fossils. One specimen contained both valves of *Macoma Baltica*, Linn, and another, *Modiolaria lævigata*, Gray. Clay stones with one or both valves of *Portlandia Arctica* are rather common in the clay-pit on Liberty street, Danvers. Near Elliott street, Danvers, the lower part of Folly hill slopes into the valley near the bed of Frost Fish brook. The upper part of the bank of the brook is boulder-till, which reaches to the top of the hill, and beneath it is found a well-bedded reddish-gray clay. In the bottom of a deep ditch cut through the bank the blue clays occur. Presumably these are leda-clays, although no fossils have been found in them.

The upper boulder-till covering these clays is a comparatively loose yellowish-red gravel packed hard and with no stratification of its members. It contains many well-glaciated, scratched, smoothed, and even rudely polished boulders of considerable size. Very rarely are small boulders and pebbles found to be glaciated in this form of till.

In September, 1903, the clay-beds at Danvers were again visited and clay-stones were collected, some of which contained fossils, the larger number being *Portlandia Arctica*, *Lyonsia arenosa*, and *Saxicava Arctica*.[1] Two of the clay-stones contain an annelid worm-case of an undeterminable species. Later in the month the Richard Graham clay-pit at Lynn was inspected, and a large bed of fossil starfish was discovered. (See Fig. 202.) Specimens were sent to Professor A. E. Verrill of New Haven, Conn., for identification, and were pronounced *Asterias stellionura*, Poiret; *Asteracanthion Lincki*, Mühler. He wrote as follows:

"The pedicellariæ, both major and minor, are remarkably well preserved and very characteristic. On the *Asteracanthion*, the latter form large and dense clusters around all the spines, and they are unusually acute. The same appears in your fossils. The major ones are very large,

[1] Leda-clay fossils collected by the author. The first thirteen species were found in the clay-pit off Liberty street, Danvers. Number fourteen was found at Lynn.

(1) *Portlandia Arctica*, Gray.
(2) *Pandora clidrophora, Gouldiana*, Dall.
(3) *Lyonsia arenosa*, Mörch.
(4) *Portlandia lucida*, Loven.
(5) *Saxicava Arctica*, Linn.
(6) *Schizoporella hyalina*, Linn.?
(7) *Schizoporella hyalina*, var. *Danversiensis*, Sears.
(8) *Macoma Baltica*, Linn.
(9) *Modiolaria discors*, Loven.
(10) *Modiolaria lævigata*, Gray.
(11) *Haminea solitaria*, Say.
(12) *Cylichna oryza*, Stimpson.
(13) *Mactra polynyma*, Stimpson.
(14) *Asteracanthion Lincki*, Müller, and Trach.

ovate, sub-acute, especially along the adambulacral plates, but also many on the dorsal surfaces as in your examples. Dorsal plates are very delicate and form a slender network. Adambulacral spines are small and slender, tapered, acute, and a large tubed spine stands singly back of every 4th or 5th plate (sometimes 3d or 4th) as in yours. In all of these characters and others, it differs from *A. vulgaris*. *A. stellionura* I first took off Cape Sable, Nova Scotia, on the American side, in 1877. It was abundant in 30 to 60 fathoms, some of them growing to be over two feet across. It is a very arctic species, common at Spitzbergen and the northern Norwegian coasts. This discovery is of much interest."

From the fact that living specimens of these fossils are to be dredged from the bottom of the sea at the present time, at a depth of thirty to sixty fathoms, and that all or nearly all are arctic forms, it is fair to presume that these fossils now found at about sea-level formerly lived at a depth of sixty fathoms on the bottom of the glacial sea.[1] Such assumption would indicate that the surface of the land was formerly three hundred and sixty feet lower than at the present time, a subsidence which would cause all of Essex County and Eastern Massachusetts to sink beneath the sea. Raised sea beaches that were formed as the land was elevated may be found at intervals across the whole of Essex County, and toward the northwest into New Hampshire wherever sand-plains and gravel ridges occur. The sand-plains at Ipswich, Rowley, Byfield, Georgetown, Groveland, Lawrence, and Methuen mark various raised beaches where the waters of the glacial sea stood for a time as the country was being elevated, and this inland sea of subsidence will account for the water-worn and rounded pebbles underlying the sand-plains, showing them to be ancient sea beaches. It also accounts for the water-dressed surfaces of many outcropping ledges where the débris of erosion has been removed, leaving the bare and rounded exterior. Although the longer axes of these ledges are parallel to the line of glaciation for the region in which they occur, there are many examples in all parts of the County where the surface seemingly has been denuded by sea-action in recent times and yet exhibits no attendant features that would account for the presence of the sea at this elevation.

Summary of Subsidence and Elevation. — "The typical and common species of *Yoldia Arctica* [the *Portlandia Arctica* heretofore mentioned]

[1] During the summer of 1905, the author found in the leda clay-pit on Liberty street, Danvers, a nearly perfect valve of a species of *Thracia*, measuring 17 mm. long and 12 mm. wide.

Fig. 203. — LONGHAM BASIN, NORTH BEVERLY.
Showing escarpment at the right and in the background.

Fig. 204. — GRAVEL-PIT AT LEGG'S HILL, SALEM, SHOWING KAME GRAVELS.

live in abundance in the high arctic seas at depths from about ten to thirty meters [96 feet]. A number of high arctic species live at greater depths. The fauna of the younger Portlandia clay comprises partly the same species as the older, but in other varieties some new forms have also supervened. Thus, for instance, *Portlandia Arctica* in the older clay reaches a length of twenty-seven to twenty-eight mm.; in the younger only about eighteen mm. Further, it is to be remarked that this clay must have been deposited at some greater depth than the older clay, as is indicated by the change in the fauna."[1]

The *Portlandia Arctica* which is the older form, and now collected at Portland, Maine, and Montreal, Canada, and whose length is 27 mm. to 28 mm., accordingly must have lived on the sea bottom during the early part of the Champlain subsidence when the land had been depressed not more than one hundred feet. *Portlandia lucida*, Loven, according to Professor Brögger, occurs in the younger area clays or deep-water forms at a depth of at least two hundred and forty feet, together with *Portlandia Arctica* in its largest forms, i.e., 8 mm. to 14 mm. The *P. Arctica* and *P. lucida* found in Essex County, therefore, are forms that probably lived on the leda-clay when the subsidence was from 240 to 360 feet in depth. The younger Portlandia clay as deposited was covered up in the Terrace period by the brick clays, sands, and gravels.

Recession of the Ice-Sheet. — During the closing era of the great ice period in the Quaternary age the whole of Essex County was submerged beneath the sea. Even the highest ledges and the tops of the drumlins were beneath this waste of waters which is now known as the Champlain Sea of Subsidence. The land surface sank at least three hundred feet. As the surface was again elevated, the waters of this sea when disturbed by storms formed lines of breakers which produced well-defined beach ridges of gravel and sand. All débris was washed from the summits of outcropping ledges and drumlins, many of which were channeled and left thickly strewn with large boulders.

Post-Glacial erosion may be seen in many parts of the County. In the western part of Georgetown the Parker river has cut a passage to the sea through numerous ridges and sand-plains, and this is true of all the streams in the County. The Merrimac river with each recurring spring season cuts into the bases of the drumlins along its course, and carries the debris to the delta at its mouth. A fine example of such erosion may be

[1] Professor W. G. Brögger: Glacial Fauna of Norway and Late Glacial and Post-Glacial Changes of Level in the Kristiania Region.

seen at North Beverly, north of Dodge street, where Longham brook has cut a channel in a sand-plain for a distance of nearly a mile, leaving an escarpment from fifteen to twenty feet in height. Corrosion has widened the valley, which in the adolescent stage of the stream was grassed over and probably covered with forest trees. The Salem and Beverly Water Boards took advantage of this escarpment and ancient stream-cutting, and by building a dam created an artificial lake known as "the Longham basin," which serves the purpose of an auxiliary water supply. (See Fig. 203.)

Sea-worn gravels with round cobble-stones are a general feature of gravel-beds about the County. (See Fig. 204.) These gravels contain calcium lime in solution, which, when gravel-beds are opened, becomes carbonized, and cements the small particles of gravel together in a form of conglomerate, and often produces a crust on the outside of pebbles and boulders. The presence of this lime indicates that there may have been shell-bearing mollusks in the gravel and that the shells have been dissolved by carbonic acid percolating from the surface. Occasionally a large boulder is found in these gravels, having been dropped from the bottom of floating ice.

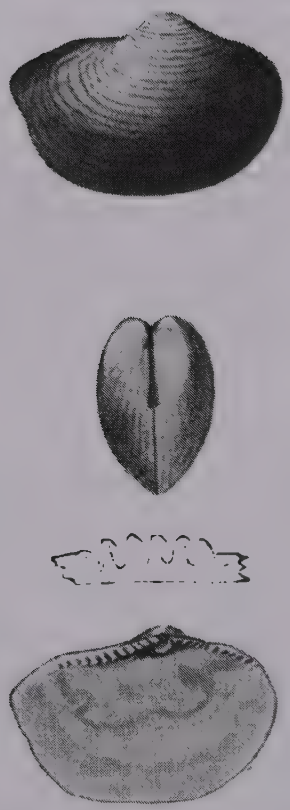


Fig. 205. — *PORTLANDIA ARCTICA*, GRAY.
From the Peabody Pottery clay-pit, Purchase Street, Danvers.

Fig. 206.

Fig. 206. GLACIAL MARINE FOSSILS FOUND IN LEDA-CLAY IN THE EDWARD CARR BRICK CLAY-PIT, LIBERTY STREET, DANVERS.

No. 1. *Portlandia Arctica*, Gray, a typical specimen of the largest size, 11½ mm. long 8 mm. wide.

Nos. 1a and 1b. *Portlandia Arctica*, Gray, greatly enlarged, showing hinge area with teeth; 1a, upper hinge; 1b, lower hinge.

No. 2. *Pandora olidrophora*, *Gouldiana*, Dall., 23 mm. long, 15 mm. wide.

No. 3. *Modiolaria discors*, Loven., 10 mm. long, 6 mm. wide.

No. 4. *Saxicava Arctica*, Linn., 23½ mm. long, 11 mm. wide.

No. 5. *Lyonsia arenosa*, Morch., 19 mm. long, 11 mm. wide.

No. 5a. *Mactra luteola*, Loven., ? in a clay stone.

No. 6. *Cylichna orizá*, Stimpson, 4½ mm. long, 2½ mm. wide.

No. 7. *Haminea solitaria*, Say., 2 mm. long, 1½ mm. wide.

No. 8. *Schizoporella hyalina*, Linn., cluster 3 mm. long, 3 mm. wide.

No. 9. *Schizoporella hyalina*, var. *Danversiensis*, Sears, elongated colony, 4½ mm. long.

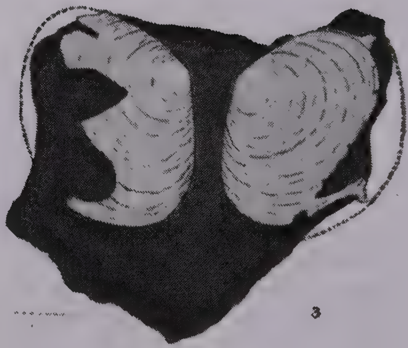
CHAPTER XII

PALEONTOLOGY OF THE CAMBRIAN ROCKS

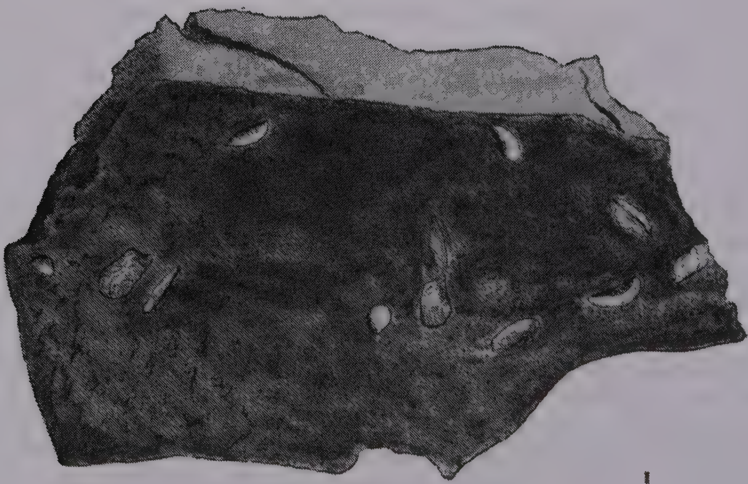
NUMEROUS markings in the limestone at East point, Nahant, were discovered in 1887, by the author, and for the first time considered to be fragments of fossils. The geologists of Massachusetts did not coincide, even after a piece of the limestone had been ground to a flat surface and polished, and the fossil fragments thickly scattered over the surface had been closely inspected. The polished specimen was then placed in the geological cabinet at the museum of the Peabody Academy of Science in Salem. In 1889, Dr. Aug. F. Foerste, the eminent paleontologist, then a student at Harvard University, collected a series of these fossils, and published a paper in the Proceedings of the Boston Society of Natural History (Vol. XXIV, pp. 261–263), in which he identified the species discovered in 1887 as *Hyolithes inequilateralis*, a type distinct from *Hyolithes princeps*. The name *inequilateralis* was not generally accepted for the species, and *princeps*, Billings, has been assigned. Since 1889 the author has collected several hundred specimens and fragments of fossils in the Cambrian limestones at Nahant, many of them being new to Essex County, and all of which are now preserved in the geological cabinets of the Peabody Academy of Science. For a detailed account of the fossils shown in Fig. 209, with the exceptions of *Scenella* and *Fordilla*, the reader is referred to a paper by Dr. A. W. Grabeau on the "Paleontology of the Cambrian Terrenes of the Boston Basin," published in "Occasional Papers of the Boston Society of Natural History," Vol. I, part III, pp. 605–656. Dr. Grabeau received the fossils used in the preparation of his paper with the understanding that his material should also be available for this work.

Outcrops of Cambrian fossiliferous limestone occur on the extreme outer portion of East point, Nahant, where the fossil horizon occurs from ten feet above mean sea-level and extends twelve feet up the face of the cliff. The beds are interstratified limestone, slate, and chert — an impure quartzite. Here fossils of *Hyolithes*, several species of brachipods and *Stenotheca*, have been found. Another outcrop of this fossiliferous limestone occurs on the ocean side opposite "Maolis Spring," so-called,

2



3



1

Fig. 207.

Fig. 207. GLACIAL MARINE FOSSILS FOUND IN LEDA-CLAY AT DANVERS.

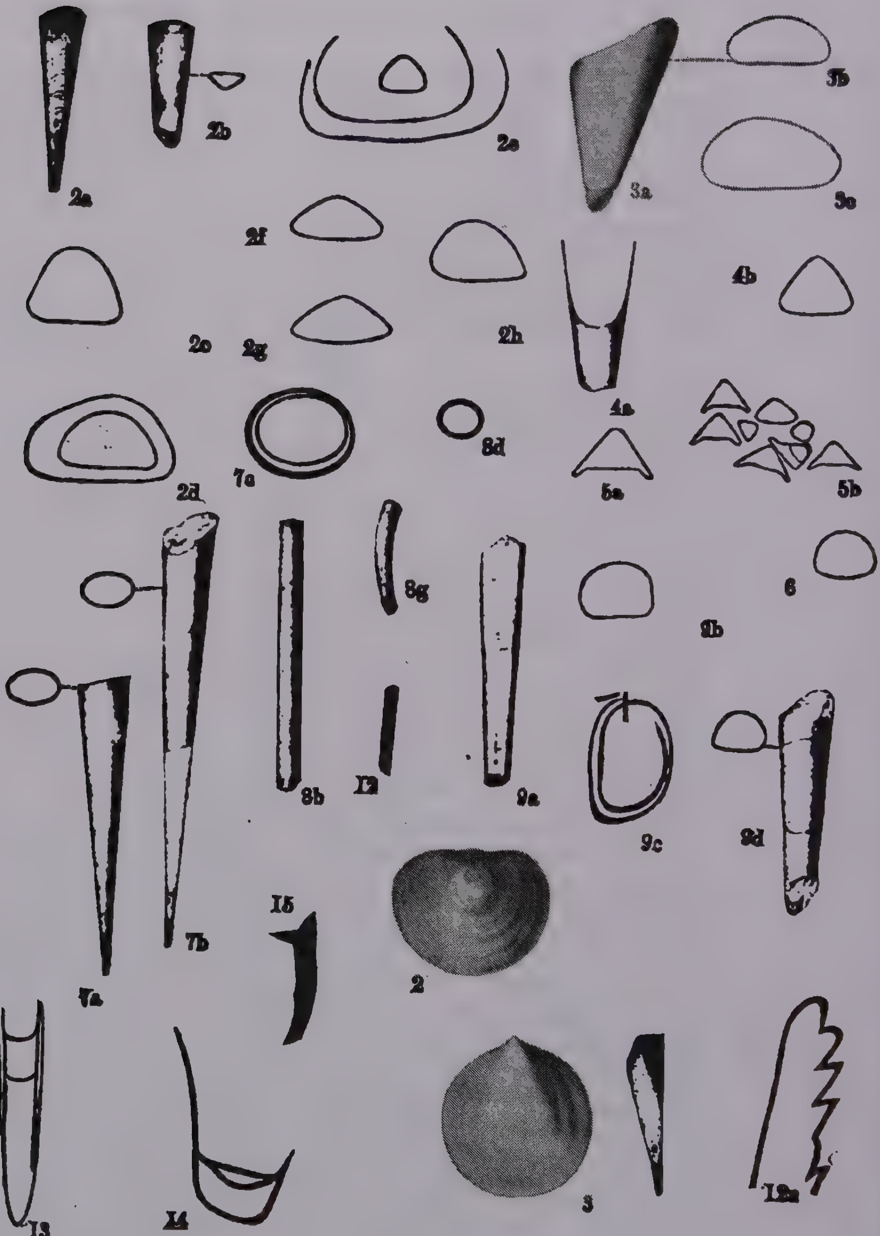
No. 1. A cleavage piece of clay with fossil *Portlandia Arctica* in position on the natural bedding of the clay. Reduced ½. From the Peabody Pottery clay pit, Purchase street, Danvers.

No. 2. *Modiolaria lævigata*, Gray, on a clay stone; length, 28 mm., width, 26 mm. From Edward Carr's clay pit, Liberty street, Danvers.

No. 3. *Macoma Baltica*, Linn., on a clay stone; length, 23¾ mm., width, 23½ mm. From Edward Carr's clay pit, Liberty street, Danvers.

where *Hyolithes princeps* occurs, specimens measuring four inches long and one inch across the basal section having been collected. Still another outcrop occurs on the Lynn harbor side of Bass point, where the beds are all below high tide or sea-level. The horizon is about eighteen inches thick, from top to bottom. This outcrop is near the causeway leading from Little Nahant to Bass point in a bank by the roadside. The fossils at this locality are Lower Cambrian and are largely *Hyolithellus micans*, Billings; *Stenotheca abrupta*, Shaler and Foerste; *Scenella Robinsoni*, Sears (the latter species named for John Robinson of Salem); *Orthotheca cylindrica*, Grabeau; and *Hyolithes impar*, Ford.

Beside Rowley Bridge street, Topsfield, on the Peterson farm, there is a series of outcrops of slate, blue limestone, chert, and ferruginous quartzite. In the limestone and the reddish slates are found fossil casts of an annelid, 4 mm. in diameter and 30 mm. in length. The blue limestone, which is probably Middle Cambrian, contains numerous minute to microscopic fossil lamellibranch shells and a sponge, *Ethmophyllum*, having only six septa. Ford's specimens have from eighteen to twenty-one septa. In the roadway east of Archelaus hill, West Newbury, occurs a series of outcrops of red limestone, slate, and quartzite. The limestone contains numerous fragments of *Hyolithes* and other Cambrian fossils. On the west bank of Batchelder's brook, east of Clay lane in Rowley, there is another outcrop of Cambrian rocks where the surface is nearly all a chert, which contains fragments of *Hyolithes*. While digging a well at the Daniel's wagon factory at Chaplinville, Rowley, a ledge was encountered which proved to be a red slate interstratified with limestone from which broken pieces of *Hyolithes* fossils were taken. Outcrops of this series of Cambrian rocks may be seen on both sides of the Boston and Newburyport turnpike at various points between Chaplinville and Glen Mills. The city ledge in South Lawrence is also a fossiliferous Cambrian rock of metamorphosed limestone interstratified with quartzite and slate. In a railroad cutting at the base of Paper Mill hill in West Peabody there are outcrops of chert, limestone, and slate, identical in character with the Cambrian fossiliferous rocks of Nahant, and although fossils have not as yet been discovered, without doubt the outcrops are of the Cambrian period. On the south side of Chestnut street, Lynnfield Centre, are numerous outcrops of white quartzite, blue slate, and limestone, which contain fossils, probably species of annelids and fucoids, which Dr. Grabeau was unable to identify. These outlying outcrops have not been examined critically, and a knowledge of their fossils is confined to a very hasty inspection.



2a
2b
2e
3a
3b
3c
2f
2c
2g
2h
4a
4b
2d
7c
8d
5a
5b
8g
6
9b
7a
7b
8b
12
9a
9c
9d
15
2
13
14
3
12a

Fig. 208.

Fig. 208. CAMBRIAN FOSSILS FROM NAHANT AND JEFFREY'S LEDGE.

No. 2. *Hyolithes princeps*, Billings.

No. 2a. Dorsal side of a young individual showing forward curving striæ and lip.

No. 2b. Fragment of a specimen showing dorsal side and cross-section. Enlarged.

No. 2c. Cross-section referred to this species obliquely cut. Enlarged from 10 mm. to 13½ mm.

No. 2d–e. Sections of large specimens from outside of Maolis spring, Nahant.

No. 2f–h. Various cross-sections, the variations in outline being due chiefly to obliquity of cut. Enlarged.

No. 3. *Hyolithes excellens*, Billings.

No. 3a. Dorsal side of specimen described. Natural size.

No. 3b. Cross-section of same.

No. 3c. Cross-section of a specimen of this species. Natural size.

No. 4. *Hyolithes Americanus*, Billings.

No. 4a. Dorsal view of the specimen described. The upper part is broken away. Enlarged.

No. 5. *Hyolithes Searsi*, Grabeau.

No. 5a. Cross-section of the largest specimen known. Natural size.

No. 5b. Group of cross-sections. Natural size.

No. 6. *Hyolithes communis*, Billings. Cross-section showing normal form.

No. 7. *Hyolithes impar*, Ford.

No. 7a. Normal shell with oval cross-section. Enlarged.

No. 7b. Fragment (restored) with cross-section. Enlarged.

No. 7c. Cross-section, enlarged.

No. 8. *Orthotheca cylindrica*, Grabeau.

No. 8b. Fragment of a large specimen. Enlarged.

No. 8d. Cross-section of the invaginated specimens. Enlarged.

No. 8g. Small curved specimen which may be of this species. Enlarged.

No. 9. *Orthotheca Emmonsi*, Ford.

No. 9a. Dorsal view of a specimen showing faint concavity. Natural size.

No. 9b. Characteristic cross-section.

No. 9c. Cross-sections of invaginated shells.

No. 9d. Ventral view of a specimen with cross-section.

No. 12. *Hyolithellus micans*, Billings. A fragment referred to this species from a red limestone boulder at Nahant. Boston Society of Natural History, Cat. No. 11,966.

No. 13. Longitudinal section of a hyolithid (?) showing two septa. From blue limestone at Jeffrey's ledge. Enlarged.

No. 14. Longitudinal section of an undetermined shell. From blue limestone at Jeffrey's ledge. Enlarged.

No. 15. Longitudinal section of a *Salterella* (?). From blue limestone at Jeffrey's ledge. Enlarged.

Recent experiments with a weak solution of muriatic acid upon the white limestone from East point, Nahant, resulted in etching out perfect specimens of *Stenotheca abrupta*, Foerste and Shaler; *Obellela crassa*, Hall; *Orthotheca cylindrica*, Grabeau; *Hyolithes princeps*, Billings; *Hyolithes Americanus*, Billings; *Hyolithes Searsi*, Grabeau; *Hyolithes communis*, Billings; *Hyolithes impar*, Ford, and an interior valve of *Fordilla Troyensis*, Walcott. Two very perfect casts of shells of *Stenotheca*, with six corrugations, have been found. They are nearly vertical. One measures 4 mm. across the base and 3 mm. in height, and has been provisionally named *Stenotheca abrupta*, Shaler and Foerste, variety *Nahantiensis*. The second measures 3 mm. across the base at its narrowest part, and is 3 mm. in height. This shell has been named *Stenotheca abrupta*, Shaler and Foerste, variety *Foerstei*, in honor of Dr. Aug. F. Foerste, the first to describe species of fossils in the County. A specimen of *Hyolithes* has been found resembling *Hyolithes princeps*, Billings, but the cross-section is in the form of a sexta and entirely different from the Billings type. This shell has been named *Hyolithes princeps*, Billings, variety *Pingreei*, in honor of Mr. David Pingree of Salem, Mass.

The more siliceous limestone on the Lynn harbor side of Nahant, when similarly treated, resulted less successfully, for the acid destroyed the fossils, and usually left only casts. However, this limestone has produced in abundance minute to ordinary specimens of *Hyolithes micans*, Billings, and *Orthotheca cylindrica*, Grabeau, of large size and in considerable number. One piece of cherty limestone contained three nearly perfect specimens of *Hyolithes communis*, Billings; and another, a doubtful specimen of *Hyolithes princeps* and a *Stenotheca* without corrugations. The dark blue limestone from the outcrop in Topsfield is so homogeneous on a freshly broken surface that it is impossible to discern recognizable species of fossils. These only may be noted in sections ground thin enough to permit light to pass through the specimen, when numerous fossils are revealed in every piece of the stone. These fossils comprise minute brachiopods, lamellibranch shells, fossil sponges, *Hyolithes*, etc.

Fig. 209.

Fig. 209. CAMBRIAN FOSSILS FROM TOPSFIELD AND NAHANT.

No. 1. Longitudinal section of an *Ethmophyllum rarum*, Ford. From the blue lime stone on the Peterson-Towne farm, Topsfield.

No. 2. Cross-section of an *Ethmophyllum rarum*, Ford. Showing six septa. From same locality.

No. 3. Cross-section of an *Ethmophyllum*, with septa crushed and broken. From same locality.

No. 4. Section of the shell of a species of lemellibranch. From same locality.

No. 5. Section of the shell of a species of lemellibranch, showing hinge area cut obliquely. From same locality.

No. 6. Section of the shell of a species of lemellibranch, showing the hinge. From same locality.

No. 7. Section of the shell of a brachiopod ?. From same locality.

No. 8. Cast of an annelid boring? From same locality.

No. 9. Shell of *Orthotheca cylindrica*. From white limestone, Lynn harbor side of Nahant.

No. 10. Shell of *Stenotheca abrupta*, Shaler and Foerste? *Forma Nahanti*, Sears. From white limestone, East Point, Nahant.

No. 11. Shell of *Stenotheca abrupta*, Shaler and Foerste? *Forma Foerstei*, Sears. From white limestone, East Point, Nahant.

No. 12. Cast of shell of *Stenotheca abrupta*, Shaler and Foerste. From white limestone, Lynn harbor side of Nahant.

No. 13. Cast of shell of *Scenella Robinsoni*, Sears. From Lynn harbor side of Nahant.

No. 14. *Scenella varians*, Walcott. From white limestone, East Point, Nahant.

No. 15. *Fordilla Troyensis*, Walcott. Cast of the interior of the right valve enlarged. From white limestone, East Point, Nahant.

No. 16. *Hyolithes princeps*, Billings. *Forma Pingreei*, Sears. From East Point, Nahant.

Appendix A

SURFACE AREAS

Table showing number of square miles and acres of territory in each of the seven cities and twenty-eight towns in Essex County, Massachusetts, in the year 1903, together with the areas covered by water, swamps, and highways.

Cities and Towns in the County	Area in Square Miles	Area in Acres
Amesbury	14	8,960
Andover	33	21,120
Beverly	20	12,800
Boxford	24	15,360
Bradford	7	4,480
Danvers	14	8,960
Essex	18	11,520
Georgetown	11	7,040
Groveland	7	4,480
Gloucester	34	21,760
Hamilton	15	9,600
Haverhill	28	17,920
Ipswich	41	26,240
Lawrence	8	5,120
Lynn	12	7,680
Lynnfield	10	6,400
Merrimac	9	5,760
Methuen	24	15,360
Middleton	16	10,240
Manchester	9	5,760
Marblehead	6	3,840
Newburyport	18	11,280
Newbury	27	17,280
North Andover	28	17,920
Peabody	17	10,880
Rockport	7	4,480
Rowley	19	12,160
Salem	9	5,760

SURFACE AREAS. *(Continued.)*

Cities and Towns in the County	Area in Square Miles	Area in Acres
Saugus	12	7,680
Salisbury	18	12,500
Swampscott	3	1,920
Topsfield	13	8,320
Wenham	9	5,760
West Newbury	15	9,600
Nahant	1	640
Totals	556	355,840

	Acres.
Tidal marsh	21,789
Tidal river valleys and bays	18,000
Peat swamps having a depth of 6 to 15 feet	16,500
Fresh-water meadows covered by water in the spring	16,500
Parks and roads (in 1898)	8,000
Total	80,789
Assessable land consisting of village and city sites, uplands, woods, and tillage	275,051

Appendix B

ELEVATION AND LOCATION OF THE DRUMLINS IN ESSEX COUNTY

	Elevation above Mean Sea-Level
	Feet
Archelaus hill, West Newbury	240
Asleb hill, North Andover	240
Ayer's hill, Haverhill and Methuen	320
Bald hill, Boxford	240
Bald Pate hill, Georgetown	340
Bare hill, Danvers	240
Bare hill, Methuen	360
Bare hill, Topsfield	140
Bartholomew's hill, Ipswich	180
Batt's hill, Salisbury	160
Beach hill, Salisbury	200
Bear hill, Merrimac	240
Bear hill, North Andover	360
Berry's hill, Boxford	200
Blaisdell's hill, Merrimac	180
Boston hill, North Andover	380
Brake hill, West Newbury	240
Brandy Brow hill, Merrimac	258
Brown's hill, Hamilton	180
Brown's hill, Ipswich	100
Brown's hill, South Groveland	220
Browne's hill, Groveland	200
Burying Ground hill, Amesbury	180
Bush hill, Ipswich	140
Bush hill, Merrimac	260
Castle hill, Ipswich	140
Cheney's hill, Groveland	140
Clay Pits hill, North Andover	240
Cook's hill, Danvers	200
Corliss' hill, Haverhill	280
Crane Neck hill, West Newbury	234
Crowninshield hill, Topsfield	260
Cutler's hill, Hamilton	140
Elliott's hill, Haverhill	220

ELEVATION AND LOCATION OF THE DRUMLINS IN ESSEX COUNTY *(Continued)*

	Elevation above Mean Sea-Level
	Feet
Fair Maid's hill, Danvers	160
Farm hill, West Newbury	200
Ferncroft, or Preston's hill, Danvers	180
Folly hill, Danvers	200
Foster's hill, North Andover	240
Golden hill, Haverhill	253
Goodale's hill, Peabody	160
Grape hill, Salisbury and Seabrook	240
Great hill, Haverhill	340
Great hill, Topsfield	240
Hall's hill, Amesbury	200
Hardy's hill, Groveland	180
Harris' hill, Methuen	300
Hathorne or Asylum hill, Danvers	280
Head's hill, Bradford	272
Heartbreak hill, Ipswich	160
Highlands hill, Merrimac	270
Hill Dale, Haverhill	240
Holt's hill, Andover	400
Hopkins' hill, Groveland	235
Howlett's hill, Topsfield	180
Huckleberry hill, Haverhill	240
Hunslow hill, Rowley	180
Hunting hill, Haverhill	180
Hutchings' hill, Groveland	200
Ilsley's hill, West Newbury	200
Indian hill, West Newbury	180
Jewett's hill, Rowley	160
Job's hill, Haverhill	260
Kimball's hill, Haverhill	240
Kimball's hill, North Beverly	160
King's hill, West Peabody	200
Lindall hill, Danvers	120
Little Neck, Ipswich	80
Little Turner's hill, Ipswich	140
Long hill, Georgetown	200
Long hill, Merrimac	120
Long hill, West Gloucester	160
Long hill, West Newbury	200
Lone Tree hill, Methuen	180
Lummus' hill, Hamilton	140

ELEVATION AND LOCATION OF THE DRUMLINS IN ESSEX COUNTY *(Continued)*

	Elevation above Mean Sea-Level
	Feet
Mears' hill, Essex	160
Meeting-house hill, Methuen	220
Mills' hill, North Andover	300
Moulton's hill, Hamilton	100
Mussey hill, Ipswich	180
Nichols' or Dale's hill, Danvers	200
North Ridge, Jeffrey's Neck, Ipswich	120
Old Town hill, Newbury	140
Osgood's hill, North Andover	380
Ox Pasture hill, Rowley	180
Paper Mill hill, West Peabody	200
Parsonage hill, Haverhill	233
Perkins' hill, Essex	180
Perkins' hill, Topsfield	200
Perry's hill, Groveland	180
Pigeon hill, Rockport	180
Pine hill, Andover	300
Pine hill, Lynnfield	200
Pine hill, South Groveland	100
Pingree's hill, Topsfield	260
Pipe Stave hill, West Newbury	180
Plover hill, Great Neck, Ipswich	120
Pole hill, Andover	140
Pond hill, Amesbury	200
Powder House hill, Amesbury	140
Powder House hill, Methuen	200
Powow hill, Amesbury	330
Prospect hill, Lawrence	140
Prospect hill, Rowley	264
Putnam's hill, Danvers	200
Red Oak hill, Merrimac	308
Red Root hill, Hamilton	160
Reservoir hill, Lawrence	140
Reservoir hill, South Groveland	240
Ring's hill, Amesbury	280
Russell's hill, North Andover	300
Sagamore hill, Hamilton	200
Saltonstall's hill, Haverhill	290
Sargent's hill, Amesbury	240
School House hill, North Andover	200
Scotland hill, Methuen	280

ELEVATION AND LOCATION OF THE DRUMLINS IN ESSEX COUNTY *(Continued)*

	Elevation above Mean Sea-Level
	Feet
Scott's hill, Ipswich	180
Silver hill, Haverhill	278
Smith's hill, Peabody	180
Solomon's hill, Danvers	280
South Scotland hill, Haverhill	320
Spofford's hill, Boxford	220
Steep hill, Castle Neck, Ipswich	120
Stiles' hill, Boxford	300
Sutton's hill, North Andover	220
Swan's hill, Groveland	220
The hill, northwest of Kenoza lake, Haverhill	320
Thomas' hill, Peabody	220
Tilton's hill, East Ipswich	160
Timber hill, Ipswich	140
Titcomb's hill, Merrimac	220
Town Farm hill, Methuen	320
Town hill, Ipswich	160
Turkey hill, Haverhill	250
Turkey hill, Ipswich	240
Turkey hill, Merrimac	240
Turkey hill, Newburyport	140
Turner's hill, Ipswich	260
Tyler's hill, North Andover	200
Upton's hill, Peabody	200
Vineyard hill, Hamilton	120
Walden hill, Peabody	220
West Meadow hill, Haverhill	337
Whipple's hill, Danvers	160
White's hill, Essex	160
Whittier's hill, Amesbury	200
Whittier's hill, Haverhill	255
Wilkins' hill, Middleton	160
Will's hill, Middleton	220
Willow Dale hill, Hamilton	200
Weir hill, North Andover	300
Wood hill, Andover	340
Woodbury's hill, Hamilton	120
Woodchuck hill, North Andover	320

Whole number of drumlins in Essex County, 193. Number of drumlins having names, 157.

Appendix C

ELEVATION AND LOCATION OF BED-ROCK HILLS, BARE OR WITH A THIN COATING OF DRIFT UPON THEM.

	Elevation above Mean Sea-level
	Feet
Bald hill, Centreville, Beverly, a nearly bare ledge of akerite syenite. .	120
Castle hill, Saugus, a nearly bare ledge of rhyolite	280
High Rock, Lynn, a nearly bare ledge of rhyolite	185
Mount Spicket, Lynn, a nearly bare ledge of hornblende granite . . .	278
Legg's hill, Salem, a bare ledge of hornblende diorite	140
Castle hill, Salem, a nearly bare ledge of hornblende diorite	65
Poole's hill, Rockport, a nearly bare ledge of hornblende granite . . .	180
Railcut hill, Gloucester, a nearly bare ledge of hornblende granite . .	180
Thompson's hill, West Gloucester, a nearly bare ledge of hornblende granite	220
Moses' hill, Manchester, a nearly bare ledge of hornblende granite . .	180
Wyman's hill, Manchester, a nearly bare ledge of hornblende granite .	200
Mount Ann, Gloucester, a bare ledge of hornblende granite	240
Uptack hill, Groveland, an early bare ledge of Cambrian sedimentary rock	220
Ship Rock, Peabody, a boulder upon a bed-rock of hornblende granite	160
Mount Pleasant, Peabody, a nearly bare ledge of hornblende granite .	140
Robin Rock, South Lynnfield, a hornblende granite quarry	140

Appendix D

LAKES AND PONDS IN ESSEX COUNTY

There are eighty lakes and ponds in Essex County, including dammed streams producing mill-ponds and water-supply reservoirs. The number of acres covered by each pond in the following list is closely approximated, as no exact survey has ever been made. Four quite distinct benches or levels extend across the County on which nearly all of the lakes and ponds are situated. The first being from three or four feet to ten feet above sea-level; the second, about forty feet above sea-level; the third, from sixty to eighty feet above sea-level; and the fourth, from one hundred to one hundred and forty feet above sea-level. It has not seemed desirable to enumerate in this list all of the mill-ponds in the County, many of which are no longer in use, while others are being formed from year to year.

Name of Pond and Location	Height above Mean Sea-Level	Area
	Feet	Acres
Niles' pond, East Gloucester	3 or 4	20
Phillips' pond, Swampscott	5	variable
Bear pond, Nahant	6	18
Clark's pond, Jeffrey's Neck, Ipswich	less than 2	25
Cape pond, Rockport	40	70
Chebacco lake, Essex	40	170
Beck's pond, Hamilton	40	43
Bound pond, Hamilton	40	35
Gravel pond, Hamilton	40	25
Coy's pond, East Wenham	40	30
Pleasant pond, Wenham and Hamilton	40	35
Beaver pond, Beverly	40	20
Norwood's pond, Beverly	40	60
Muddy pond, Wenham	40	20
Cedar pond, Wenham	45	8¼
Wenham lake, Beverly and Wenham	40	250.6
Legg's Hill pond, Salem	40	3
Glenmere or Floating Bridge pond, Lynn	40	8
Wyoma lake, Lynn	80	35
Wenuchus lake or Flax pond, Lynn	40	56

LAKES AND PONDS IN ESSEX COUNTY *(Continued)*

Name of Pond and Location	Elevation above Mean Sea-level	Area
	Feet	*Acres*
Breed's pond, Lynn	60	52
Birch pond, Lynn	60	44
Walden pond, Saugus	80 to 100	variable
Hawkes' pond, Saugus	80 to 100	variable
Spring pond, Salem	60	30
Brown's pond, Peabody	60	25
Cedar pond, Peabody	80	17½
Winona lake or Lily pond, Peabody	80	10
Bartholomew's pond, Peabody	80	8½
Suntaug lake, Peabody and Lynnfield	100	165
Bancroft's pond, Peabody	20	18
Pillings' pond, Lynnfield	80	59¾
Forest lake, Middleton	80	100
Hood's pond, Topsfield and Ipswich	80	68
Kimball's pond, Amesbury and Merrimac	80	306
Gardner lake, Amesbury	80	52
Hackett's pond, Andover	100	220
Foster's pond, Andover	80	105
Pomp's pond, Andover	100	37
Low's Saw-mill pond, Boxford	100	50
Crooked pond, Boxford	160	12
Stevens' pond, Boxford	100	13
Four Mile pond, Boxford	100	42
Spofford's pond, Boxford	100	22
Stiles' pond, Boxford	100	60
Bald Pate or Perley's pond, Boxford	100	54
Johnson's pond, Boxford and Groveland	100	200
Crane pond, Groveland	60	20
Lake Cochichewick or Great pond, North Andover	180	450
Lake Saltonstall or Plug pond, Haverhill	118	41
Kenoza lake, Haverhill	112	234
Round pond, Haverhill	148	38
Crystal lake or Creek pond, Haverhill	148	175
South or Youth's pond, Methuen	140	45
Mystic pond, Methuen	140	18
Stevens' pond, Methuen	140	18
Pentucket pond, Georgetown	140	58
Rock pond, Georgetown	140	75
Chadwick's pond, Bradford	100	126

Appendix E

GEOLOGICAL SUCCESSION OF THE ROCK FORMATIONS OF ESSEX COUNTY, MASSACHUSETTS.

Archean or Pre-Cambrian:

Arkose, conglomerate granite, hornblende epidote gneiss.

Lower Cambrian or Algonkian:

Metamorphosed slates, sandstones, conglomerates.

Paleozoic:

Cambrian white limestones, chert, slate quartzite.
Blue limestone, red slate, ferruginous quartzite.

Post-Cambrian:

Plutonic eruptives.
Hornblende diorite, amphibolite gneiss.
Diallage gabbro, dike rocks including serpentine, peridotites.
Quartz augite hornblende diorites with foliated forms.
Hornblende granite, aplite granite dikes.
Porphyritic hornblende granite with gneissic forms.
Muscovite biotite granite, foliated muscovite biotite granite.

Syenite Series:

Essexite group. Salemite.
Nepheline syenite, pulaskite, hedrumite.
Augite syenite (akerite), quartz augite syenite.
Quartz mica hornblende syenite (nordmarkite).
Ægirine syenite, arfvedsonite, quartz mica syenite.

Dike Rocks of the Syenite Series:

Camptonite.
Acmite, ægirine tinguaite.
Analcite tinguaite.
Sölvsbergite (Bostonite porphyry).

Kersanite.
Keratophyre — a surface lava flow.
Umptekite or hornblende gabbro series.

Ancient Volcanic Rocks:

Aporhyolite — massive igneous rocks.
Aporhyolite agglomerates, breccias, foliated or banded aporhyolites.
Porphyritic aporhyolite, felsitic rhyolite, quartz porphyry aporhyolite, conglomerate aporhyolite, lithophase.
Aporhyolite dike rocks.
Felsitic porphyry.
Quartz porphyry.
Liparite.
Vitrophyre.

Superficial Unconsolidated Rocks:

Cenozoic Pleistocene Era.
Till or ground moraine, older diluvium.
Glacial marine clay containing fossils.
Boulder-till of drumlins.
Terminal moraines, eskers, later clay-beds formed in ancient estuaries.

Physozoic Era.
Post-Terrace Era.
Peat-beds, river alluvium, silts.

Present Epoch.
Evidence of subsidence, submerged forest trees, drowned stream- and river-valleys, recently formed deltas, sand beaches and dunes.

Appendix F

CHEMICAL ANALYSES OF THE ROCKS OF ESSEX COUNTY, BY PROFESSOR HENRY S. WASHINGTON, OF LOCUST, N. J.

TABLE I.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
SiO_2	77.61	77.14	76.49	73.93	71.40	70.64	68.88	68.36	67.35	66.60	64.28	63.71
TiO_2	0.25	0.29	trace	0.18	.....	0.90	0.19	trace	0.60	0.76	0.50	trace
ZrO_2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Al_2O_3	11.94	12.24	11.89	12.29	14.76	15.34	14.77	16.58	15.05	15.05	15.97	18.30
Fe_2O_3	0.55	0.29	1.16	2.91	1.68	1.83	0.64	0.90	1.23	1.07	2.91	2.08
FeO	0.87	1.04	1.56	1.55	0.72	1.10	4.64	3.24	4.76	4.42	3.18	2.52
MnO	trace	trace	trace	trace	trace	trace	trace	trace	0.05	trace	trace	trace
MgO	trace	0.06	trace	0.04	0.55	0.52	0.37	0.45	0.03	0.36	0.03	0.09
CaO	0.31	0.35	0.14	0.31	0.10	1.24	1.74	1.85	0.55	2.21	0.85	1.18
BaO	.....	.....	.....	none	.....	.....	.....	.....	.....	none	none	.....
Na_2O	3.80	4.64	4.03	4.66	4.79	5.23	3.83	3.97	4.42	4.03	7.28	6.39
K_2O	4.98	4.47	5.00	4.63	5.16	3.55	4.97	5.27	6.08	5.42	5.07	6.21
H_2O (110°)	trace	trace	0.12	.....	.....	0.14	0.06	0.18	0.16	.....	.....	0.09
H_2O (ignit)	0.23	0.14	0.38	0.41	1.46	0.38	0.24	0.17	0.17	0.41	0.20	0.17
P_2O_5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.08	.....
	100.54	100.66	100.77	100.91	100.62	100.87	100.33	100.97	100.45	100.33	100.33	100.74
Sp. Gr.	2.618		2.650	2.642		2.632	2.696		2.600	2.612	2.703	2.686
at	18° C.		13° C.	22° C.		12.5° C.	12° C		17° C.	17° C.	22° C.	12° C.

TABLE I — *Continued.*

	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV
SiO_2	63.09	61.05	60.05	59.31	58.77	56.75	51.82	47.12	46.99	46.59	45.32	43.73
TiO_2	0.45	0.34	0.11	0.32	0.31	0.30	2.15	3.27	2.02	1.41	1.94	4.23
ZrO_2	0.06	.....	.....	.....	0.11	.....	.....	.....	.....	.....	.....	.....
Al_2O_3	18.50	18.81	19.97	22.50	22.64	20.69	17.06	14.43	17.94	17.55	18.99	20.17
Fe_2O_3	2.90	2.02	4.32	1.93	1.54	3.52	1.97	3.33	2.56	1.68	3.78	4.32
FeO	1.36	3.06	1.04	1.40	1.04	0.59	8.60	11.71	7.56	10.46	9.78	6.93
MnO	trace	trace	0.79	trace	trace	trace	trace	.....	.....	.....	.....	.....
MgO	0.16	0.42	0.23	0.17	0.19	0.11	4.87	6.05	3.22	7.76	4.68	3.91
CaO	1.00	1.30	0.91	0.46	0.74	0.37	8.59	9.63	7.85	10.64	9.19	10.90
BaO	.....	none	.....	.....	none	none	.....	.....	none	.....	.....	.....
Na_2O	7.25	6.56	7.69	7.98	9.62	11.45	3.44	2.58	6.35	3.31	3.78	2.42
K_2O	5.23	6.02	3.24	4.08	4.89	2.90	1.77	1.11	2.62	0.72	2.12	1.45
H_2O (110°)	0.21	.....	0.15	0.15	0.07	0.04	0.11	0.28	.....	0.10	0.09	0.08
H_2O (ignit)	0.62	0.78	1.26	1.12	0.90	3.18	0.20	0.34	0.65	0.07	0.31	1.02
P_2O_5	.....	.....	Cl=0.28	.....	.....	Cl=0.28	.....	.....	0.94	.....	.....	0.15
	100.83	100.36	100.04	99.42	100.82	100.18	100.58	99.85	99.60	100.29	99.98	99.40
Sp. Gr.		2.655	2.708	2.599	2.596	2.474		3.072	2.919	3.047	2.975	3.058
at		12° C.	......	12° C.	11° C.	22° C.		12° C.	12° C.	11° C.	11° C.	11° C.

I. Granite. Rockport.
II. Aplite (mean). Bass Rocks.
III. Paisanite. Magnolia.
IV. Granite. Quincy. (Blue hills.)
V. Keratophyre. Marblehead Neck.
VI. Rhyolite. Marblehead Neck.
VII. Quartz syenite porphyry. Squam light.
VIII. Nordmarkite. Wolf hill.
IX. Enclosure in Granite. Rockport.
X. Akerite. Gloucester.
XI. Sölvsbergite. Andrews' point.
XII. Pulaskite. Salem Neck.
XIII. Pulaskite. Salem Neck.
XIV. Sölvsbergite. Coney island.
XV. Tinguaite. Gale's point. (Eakle.)
XVI. Foyaite. Great Haste ledge.
XVII. Foyaite. Salem Neck.
XVIII. Tinguaite. Pickard's point.
XIX. Diorite. Marblehead.
XX. Diabase. Rockport.
XXI. Essexite. Salem Neck.
XXII. Camptonite. Salem Neck.
XXIII. Hornblende Gabbro. Salem Neck.
XXIV. Gabbro. Nahant.

QUANTITATIVE CLASSIFICATIONS OF THE ANALYSES OF THE ROCKS OF ESSEX COUNTY.

By Professor Henry S Washington.

In the following table, the rocks of Essex County are classified according to the chemical analyses of igneous rocks arranged by Dr. Henry S. Washington, in Professional Paper No. 14, published in 1903, by the United States Geological Survey.

Class I, order 4, rang 1, subrang 3, Liperose.
Hornblende granite, Rockport.
Paisanite, Magnolia.
Quartz syenite, Pigeon Hill quarry, Rockport.
Aplite, Bass rocks, East Gloucester.
Keratophyre, Marblehead Neck.
Keratophyre, Marblehead Neck, Boden's point.

Class I, order 4, rang 2, subrang 3 Toscanose.
Quartz syenite porphyry, near Squam light, Cape Ann.
Nordmarkite, Wolf Hill, Gloucester.
Akerite, Gloucester.

Class I, order 5, rang 1, subrang 4, Phlegrose.
Hedrumitic pulaskite, Salem Neck.

Class I, order 5, rang 1, subrang 4, Nordmarkose.
Pulaskite, Salem Neck.
Sölvsbergite syenite porphyry, Coney island, Salem harbor.
Biotite tinguaite, Gale's point, Manchester.
Foyaite, Great Haste ledge, Salem harbor.

Class I, order 6, rang 1, subrang 4, Miaskose.
Foyaite, Salem Neck.
Analcite tinguaite, Pickard's point, Manchester.

Class II, order 5, rang 1, subrang 4, Umptekose.
Glaucophane-sölvsbergite, Andrews' point, Cape Ann.

Class II, order 5, rang 3, subrang 4, Andose.
Diorite, Peach's point, Marblehead.

Class II, order 5, rang 4, subrang 3, Hessose.
Gabbro, Nahant.

Class II, order 6, rang 2, subrang 4, Essexose.
Essexite, Salem Neck.

Class II, order 6, rang 3, subrang 4, Salemose.
Hornblende gabbro, Salem Neck.

Class III, order 5, rang 3, subrang 4, Camptonose.
Diabase, Rockport.

Class III, order 5, rang 4, subrang 3, Auvergnose.
Camptonite, Salem Neck.

Appendix G

BIBLIOGRAPHY

Agassiz, Professor Louis. Fossiliferous strata at Nahant. Proc. of Boston Soc. of Nat. Hist., Vol. 3, p. 341.

Agassiz, Professor Louis. Mansfield coal formation at Nahant. Proc. of Am. Academy, Vol. 1, p. 270.

Alger, Barden, Gregory, and others. Geology and mineralogy of Rockport. Proc. of Essex Institute, Vol. 3, pp. 205–206.

Balch, David M. Anorthite from Swampscott. Am. Jour. of Science and Arts, 2d ser., Vol. 33, p. 348.

Balch, David M. On the sodalite at Salem. Proc. of Essex Institute, Vol. 4, p. 3.

Barden, S. Lithology and mineralogy of Rockport. Proc. of Essex Institute, Vol. 3, p. 231.

Barden, S. Serpentine in Lynnfield. Proc. of Essex Institute, Vol. 3, p. 89.

Barden, S. Ship rock, etc. Proc. of Essex Institute, Vol. 4, p. liv.

Barden, S., and Perkins, H. C. Devil's den. Proc. of Essex Institute, Vol. 4, p. lxi.

Bicknell, E. Eozoon Canandense. Bull. of Essex Institute, Vol. 1, p. 144.

Burbank, L. S. On the Eozoon Canandense in the crystalline limestone in Eastern Massachusetts. Proc. of Am. Assoc. for Advancement of Science, Vol. 20, p. 262.

Chute, A. P. Minerals of Lynnfield. Proc. of Essex Institute, Vol. 2, p. 47.

Chute, A. P., and Streeter, G. L. Cancrinite, pyrite and zircon in Salem. Proc. of Essex Institute, Vol. 1, pp. 151–153.

Cook, J. P., Jr. Danalite, a new mineral species from the granite of Rockport. Am. Jour. of Science and Arts, 2d ser., Vol. 42, p. 73.

Cook, J. P., Jr. On cryophyllite, a new mineral species of the mica family with some associated minerals in the granite of Rockport. Am. Jour. of Science and Arts, 2d ser., Vol. 43, p. 217.

Cornelius, Rev. E. Salem syenite, jasper, amygdaloid, etc. Am. Jour. of Science and Arts, 1st ser., Vol. 3, p. 232.

Crosby, Professor W. O. Report on the geology of Massachusetts with geological map of Boston and vicinity, 1877–1880. Proc. of Boston Soc. of Nat. Hist. Occasional papers, III.

Diller, J. S. Felsites and their associated rocks north of Boston. Bull. of Museum of Comp. Zoology, Harv. Coll. Geological Series, Vol. 1, No. 2.

Dodge, W. W. North Gooseberry island in Salem harbor. Proc. Boston Soc. of Nat. Hist., Vol. 21, p. 214.

Emerson, G. H.. On magnetite and an unknown mineral at Nahant. Proc. of Essex Institute, Vol. 4, p. 6.

Foerste, Aug. F. Paleontological horizon of the limestone at Nahant. Proc. of Boston Soc. of Nat. Hist., Vol. 25, p. 261.

Georgetown, Mineral paint mine. Proc. of Essex Institute, Vol. 4, p. clii.

Gregory, J. J. H. Geology of Lynn. Proc. of Essex Institute, Vol. 3, p. 101.

Gregory, J. J. H. Geology of Marblehead. Bull. of Essex Institute, Vol. 9, p. 150.

Gregory, J. J. H. Geology of Marblehead. Proc. of Essex Institute, Vol. 2, p. 306.

Gregory, J. J. H. Geology of Marblehead. Proc. of Essex Institute, Vol. 6, p. 43.

Gregory, J. J. H. Geology of Middleton. Proc. of Essex Institute, Vol. 3, p. 109.

Gregory, J. J. H. Geology of the coast region. Proc. of Essex Institute, Vol. 3, p. 96.

Gregory, J. J. H. Geology of Powow hill. Proc. of Essex Institute, Vol. 3, p. 269.

Grabeau, Dr. Amadeus W. Cambrian fossils. Occasional Papers of the Boston Soc. of Nat. Hist., Vol. 4, p. 605 et seq.

Gulliver, F. P. Tombolas at Nahant and Marblehead. Proc. Am. Acad. of Arts and Sciences, Vol. 34, p. 193.

Hayes, A. A. Serpentine of Lynnfield. Proc. of Boston Soc. of Nat. Hist., Vol. 5, p. 359.

Hitchcock, C. H. Geology of Andover. Proc. of Essex Institute, Vol. 5, p. 157.

Hitchcock, Edward. Report on the geology of Massachusetts. Am. Jour. of Science and Arts, 1st ser., Vol. 22, p. 1.

Hunt, T. Sterry. Crystalline limestones of Eastern Massachusetts. Am. Jour. of Science and Arts., 2d ser., Vol. 18, p. 198.

Hunt, T. Sterry. Eruptive granites of Rockport. Proc. of Boston Soc. of Nat. Hist., Vol. 15, p. 262.

Hunt, T. Sterry. Geological description of New England granite formation. Bull. of Essex Institute, Vol. 1, p. 106.

Hunt, T. Sterry. Labradorite rocks at Marblehead. Am. Jour. of Science and Arts, 2d ser., Vol. 49, p. 398.

Hunt, T. Sterry. Labradorite rocks on Marblehead Neck. Am. Jour. of Science and Arts, 2d ser., Vol 49, p. 185.

Hunt, T. Sterry. Notes on granite rocks. Am. Jour. of Science and Arts, 3d ser., Vol. 1, pp. 82–182.

Hunt, T. Sterry. Notes on the geology of Eastern Massachusetts. Bull. of Essex Institute, Vol. 3, p. 53.

Hunt, T. Sterry. On Laurentian rocks in Eastern Massachusetts. Am. Jour. of Science and Arts., 2d ser., Vol. 49, p. 75.

Hunt, T. Sterry. On the geology of the vicinity of Boston. Proc. of Boston Soc. of Nat. Hist., Vol. 14, p. 45.

Hyatt, Professor A. Drift at Salem and Cambridge. Proc. of Boston Soc. of Nat. Hist., Vol. 12, p. 150.

Hyatt, A. Eozoon in Essex County. Bull. of Essex Institute, Vol. 2, p. 93.

Hyatt, A. Geology of Marblehead Neck. Bull. of Essex Institute, Vol. 2, p. 111.

Hyatt, A. Geology of Swampscott, etc. Proc. of Boston Soc. of Nat. Hist., Vol. 14, p. 91.

Hyatt, A. On the geological survey of Essex County. Bull. of Essex Institute, Vol. 3, p. 49.

Hyatt, A. Remarks on the porphyries of Marblehead. Proc. of Boston Soc. of Nat. Hist., Vol. 18, p. 220.

Hyatt, A., and S. Todd. Geology of Salem. Proc. of Essex Institute, Vol. 6, pp. 51–52.

Jackson, C. T. Minerals from Rockport. Proc. of Am. Academy, Vol. 6, p. 167.

Jackson, C. T. Serpentine of Lynnfield. Proc. of Boston Soc. of Nat. Hist., Vol. 5, p. 314.

Jackson, C. T. Supposed meteoric stone from Marblehead. Proc. of Boston Soc. of Nat. Hist., Vol. 6, p. 294.

Jackson, C. T. Syenite of Nahant. Proc. of Boston Soc. of Nat. Hist., Vol. 4, p. 170.

Kimball, J. P. On sodalite and elæolite from Salem. Am. Jour. of Science and Arts, 2d ser., Vol. 29, p. 65.

Knowlton, W. J. On a new mineral from Rockport. Am. Jour. of Science and Arts, 2d ser., Vol. 44, p. 224.

Lane, Alfred C. Geology of Nahant (abstract). Proc. of Boston Soc. of Nat. Hist., Vol. 25, p. 91.

Mackenzie, Samuel S. Local geology of Topsfield. Proc. of Essex Institute, Vol. 3, p. 49.

McDaniel, Rev. B. F. Geology and mineralogy in Essex County. Bull. of Essex Institute, Vol. 16, p. 133.

McDaniel, Rev. B. F. Geology and mineralogy of Newbury. Bull. of Essex Institute, Vol. 16, p. 163.

Mills, F. S. Delta plain at Andover, Mass. Am. Geologist, Vol. 32, pp. 162–170.

Mudge, Benjamin F. Geology and mineralogy of Lynnfield. Proc. of Essex Institute, Vol. 2, p. 291.

Mudge, B. F. Geology of Groveland. Proc. of Essex Institute, Vol. 2, p. 406.

Mudge, B. F. Geology of Manchester. Proc. of Essex Institute, Vol. 2, p. 39.

Mudge, B. F. Geology of Middleton. Proc. of Essex Institute, Vol. 2, p. 385.

Nichols, Andrew. Syenite of South Danvers. Proc. of Essex Institute, Vol. 1, p. 19.

Osgood, Alfred. Lead mine at Rocky hill, West Newbury. Bull. of Essex Institute, Vol. 6, p. 142.

Osgood, A. Notice of the mining lands at Newbury. Vol. 7, p. 108.

Osgood, A. Remarks on the lead ore of West Newbury. Bull. of Essex Institute, Vol. 6, p. 205.

Perkins, Henry C. Sand in Newburyport. Proc. of Essex Institute, Vol. 4, p. clxiii.

Perry, J. B. On the Eozoon limestone of Eastern Massachusetts, Proc. of Am. Assoc. for Advancement of Science, Vol. 20, p. 370.

Pickering, Charles. Boulders at Salem and Danvers. Proc. of Boston Soc. of Nat. Hist., Vol. 5, p. 24.

Pickering, Charles. Drift at Salem. Proc. of Boston Soc. of Nat. Hist., Vol. 14, p. 91.

Prescott, William. Sketch of the geology and mineralogy of the southern part of Essex County. Jour. of Essex Co. Nat. Hist. Soc., Vol. 1, p. 78.

Putnam, F. W. Phaeton rock. Bull. of Essex Institute, Vol. 3, p. 128.

Richards, R. H. On a newly discovered lead vein in Newburyport. Proc. of Boston Soc. of Nat. Hist., Vol. 17, p. 200.

Robinson, John. Account of the Agassiz boulder. Bull. of Essex Institute, Vol. 6, p. 158.

Shaler, Professor N. S. Geology of Cape Ann, Mass. U. S. Geol. Survey, 9th Rept.

Shaler, Professor N. S. Glacial beds at Gloucester. Proc. of Boston Soc. of Nat. Hist., Vol. 11, p. 27.

Shaw, Chief Justice Lemuel. Granite as a building material. Proc. of Am. Academy, Vol. 4, p. 353.

Shepard, C. U. Columbite and tin ore at Beverly. Am. Jour. of Science and Arts, 1st ser., Vol. 34, p. 403.

Shepard, C. U. Green feldspar and galena at Beverly. Am. Jour. of Science and Arts, 1st ser., Vol. 35, p. 192.

Ship Rock, The Danvers boulder. Jour. of Essex Co. Nat. Hist. Soc., Vol. 1, p. 120.

Skinner, G. W. Moraine in Beverly. Proc. of Essex Institute, Vol. 4, p. xlviii.

Swallow. Ellen H. Chemical composition of some minerals from Newburyport. Proc. of Boston Soc. of Nat. Hist., Vol. 17, p. 462.

Tarr, Ralph S. Central Massachusetts moraine. Proc. of Boston Soc. of Nat. Hist., Vol. 43, p. 141.

Tarr, R. S. Phenomenon of rifting in granite. Am. Jour. of Science, 3d ser., Vol. 41, pp. 267–272.

Tarr, R. S. Post-glacial and Interglacial changes of level at Cape Ann, Mass. Bull. of Museum of Comp. Zoology, Vol. 42, pp. 181–191.

Tenney, Sanborn. Geology of Boxford. Proc. of Essex Institute, Vol. 3, p. 85.

Todd, Samuel. Gravel pits of Topsfield. Proc. of Essex Institute, Vol. 3, p. 15.

Topsfield, Copper Mines of. Proc. of Essex Institute, Vol. 6, p. 47.

Tracy, C. M. Notice of a singular erratic in Lynn known by the name of Phaeton Rock. Bull. of Essex Institute, Vol. 1, p. 59.

Very, Jones. Wigwam rock. Bull. of Essex Institute, Vol. 3, p. 129.

Wadsworth, Dr. M. E. Notes in geology and lithology. Proc. of Boston Soc. of Nat. Hist., Vol. 21, p. 406.

Wadsworth, M. E. Notes on the petrography of Quincy and Rockport. Proc. of Boston Soc. of Nat. Hist., Vol. 19, pp. 309–316.

Wadsworth, Dr. M. E. On the so-called tremolite of Newburyport, Mass. Proc. of Boston Soc. of Nat. Hist., Vol. 19, p. 251.

Wadsworth, M. E. On the trachyte of Marblehead Neck, Mass. Proc. of Boston Soc. of Nat. Hist., Vol. 21, p. 288.

Wadsworth, M. E. Syenite and gabbro in Massachusetts. Geological Mag., 3d ser., Vol. 2, pp. 207–210.

Wadsworth, M. E. Zircon syenite from Marblehead. Harv. Univ. Bull. No. 3.

Washington, Dr. Henry S. Petrographical province of Essex County, Mass. Jour. of Geology, Vol. 6, pp. 787–808; Vol. 7, pp. 53–64; 105–121, 284–294, 463–480.

Webster, J. W. Epidote at Nahant. Am. Jour. of Science and Arts, 1st ser., Vol. 3, p. 364.

Webster, J. W. Green feldspar and zircon from Beverly. Boston Jour. of Philosophy and Arts, Vol. 1, p. 599.

Webster, J. W. Green feldspar from Beverly. Boston Jour. of Philosophy and Arts, Vol. 1, p. 390.

Webster, J. W. Remarks on the geology of Boston and vicinity, continued, Vol. 3, p. 486.

Wheatland, Dr. Henry. Mineralogy of Salem Neck. Proc. of Essex Institute, Vol. 3, p. 280.

Woodworth, J. B. Note on elevated sea beaches. Bull. of Museum of Comp. Zoology, Vol. 42, pp. 191–194.

Wright, Geo. F. Kames and moraines of New England. Proc. of Boston Soc. of Nat. Hist., Vol. 20, p. 210.

Wright, Geo. F. On Indian ridge and its continuation in Andover. Bull. of Essex Institute, Vol. 7, p. 165.

INDEX

CPSIA information can be obtained at www.ICGtesting.com
Printed in the USA
BVOW060242120912

300228BV00003B/9/P

9 781277 096330

9 781277 096330